MANAGEMENT OF ACCUMULATORS

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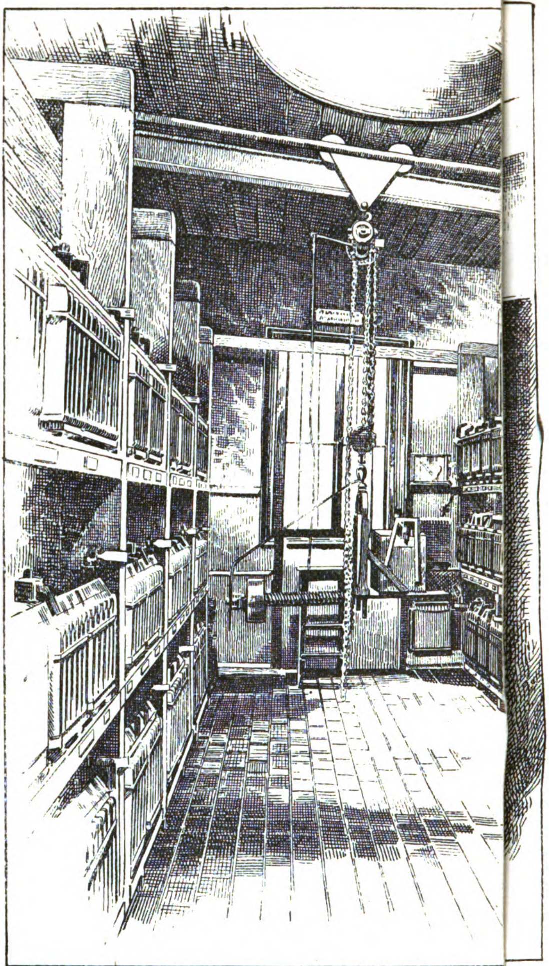

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MANAGEMENT OF ACCUMULATORS

AND

Private Electric Light Installations.

A Practical Handbook

BY

Lionel Goldsmid-Stern

SIR DAVID SALOMONS, BART., M.A., A.I.C.E., M.S.T.E.

THIRD EDITION, REVISED AND ENLARGED.

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PREFACE TO THE THIRD EDITION.

THE object of this little book is to fill a gap in practical scientific literature which is much needed. It is desired to place before readers a general knowledge of the practise of Electric Lighting and management of Accumulators, with such recommendations as are likely to assist them in obtaining success.

The first and second editions of the book were so rapidly disposed of, that it was evident a demand for such a work existed, and besides the English version, a translation has been made into the German language.

The present edition has been much enlarged and almost entirely re-written, bringing the subject down to date, and, therefore, it has been deemed advisable to alter the name of the book.

The author feels confident that if the directions here laid down are carefully followed, they will prove of great

service, and very rarely, indeed, will professional advice be required. In fact, the contents of this little book is the result of years of labour, regardless of expense, so as to insure results of a satisfactory nature, which are only possible by conducting endless experiments. The cells of the Electrical Power Storage Company, Messrs. Elwell Parker, and their type, are those here chiefly dealt with, because at the present time these are almost universally used, notwithstanding that many other types exist, and, perhaps, time may show some of these to be superior ; but that moment has not yet come.

The author feels much indebted to those friends and correspondents who have given him so many valuable suggestions, thus materially assisting him in his work.

Broomhill, Tunbridge Wells.
November, 1887.

CONTENTS.

INDEX OF TERMS.

H_2O = Water.

H_2SO_4 = Sulphuric acid.

PbO_2 = Lead pèroxide.

PbO = Lead oxide.

H = Hydrogen.

O = Oxygen

Pb = Lead.

E.M.F. = Electro-motive force, or pressure of current.

Ampère = Measure for quantity of current.

Volt = Measure for pressure of current.

Watt = Volt × Ampère = Measure of force or energy.

Electrolyte = The liquid put in a cell.

s.g. = Specific gravity.

c.p. = Candle power.

MANAGEMENT OF ACCUMULATORS.

PART I.—CELLS.

CHAPTER I.

DESCRIPTION OF CELLS AND THEIR MODE OF EMPLOYMENT.

A CELL is the receptacle for the liquid and plates, but generally the word is employed to signify the vessel with contents complete, unless the contrary is implied. A number of cells connected together form a battery, or as now is generally termed an accumulator, when the battery is a secondary one. The plates consist of positive and negative elements. All those of the same denomination in a cell are metallically joined together, but the dissimilar plates are not in contact one with the other, neither inside nor outside the cell. The plates form an electrical connection inside the cell only through the electrolyte, and outside by joining one set of plates to the other through a conductor which may be very complex, such, for example, as a long length of wire, with one or more lamps in its course. In this condition, the circuit is said to be "closed," and a current flows. When the outside conductor is broken no current

passes, and the circuit is "open." The only object in employing a number of plates of each kind, instead of one positive and one negative, is to avoid the inconvenience of using very large single plates. Cells are of two kinds—primary and secondary. The "primary" cells are made in as many ways as there are stars in the sky, but all have one characteristic—namely, that when exhausted the whole or part of the chemicals employed must be renewed, and sometimes the plates also. For practical electric lighting purposes such cells are of no value, notwithstanding the assertion of the makers of some of them to the contrary. One description might however be excepted—the chlorine cell, generally termed the "Upward cell" after the inventor. Even in this case there are drawbacks, and it cannot be employed on a large scale. It must not be supposed that a good primary battery may not one day be forthcoming, for it is quite within the bounds of possibility.

The other kind of cells are termed secondary, because without putting in fresh chemicals, they may be revived by simply passing a current through them. These cells have been very appropriately termed "reversible cells," by Mr. Fitzgerald.

It is these latter only that we shall speak of here. It will be assumed that readers of this little book have a general knowledge of electric lighting, and thus avoid going into minute details best obtained in an electrical primer.

It has become a practice amongst makers of secondary cells to call the "true positives" negative plates, and

vice versâ; therefore, not to cause confusion, the manufacturers' designations will be adhered to throughout.

The cells proper are made of glass, metal, wood lined with glass or pitch, or celluloid. For stationary work glass is by far the best, but for movable batteries, such as are required for launches, tramcars, etc., other kinds must be chosen.

The fluids, or electrolytes, which can be used are very numerous; they may be alkaline, acid, or neutral, according to the plates employed, and from other considerations.

The plates may be all metallic, or one set of metal and the other of carbon, or some suitable substance, and in some cases neither are metal.

To attempt a description of every kind of secondary cell would be of little interest in a book written solely for practical purposes, for there are but two sorts of cells which are of real value at the present time. The first has the plates composed of lead, in a spongy or granular state; and the second has lead plates (or some alloy of lead) perforated with holes, and filled with lead compounds. Of the latter type there are numerous modifications to obtain the same end. There is also a third type, where lead plates are used in conjunction with zinc ones; but as these cells cannot be reversed an indefinite number of times, owing to the fact that the zinc plates do not on each reversal keep to their original form, and to the growth of "zinc-trees," they must be excluded for electric lighting purposes on a large scale. They have a use for portable lamps and laboratory

work, being comparatively of light weight for the power contained. Thus we have two types to be considered and fully described.

The plain lead type were first shown to be reversible by Planté, although earlier workers are said to have discovered this property before him. To Faure appears to be the merit of having so modified the Planté cell as

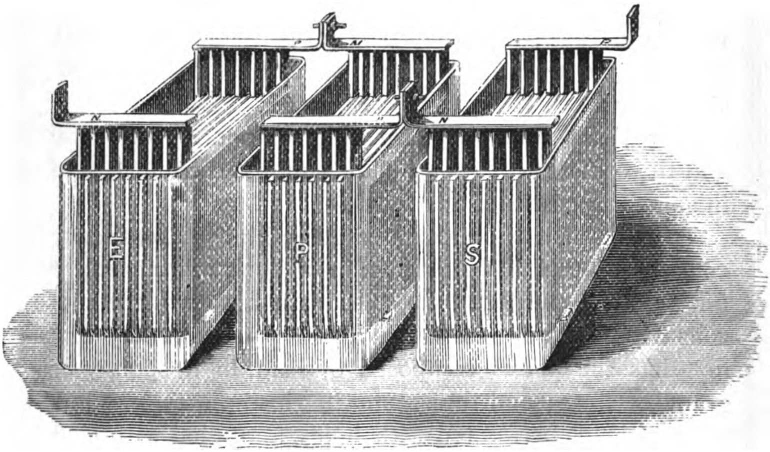


FIG. 1.—E. P. S. CELLS.

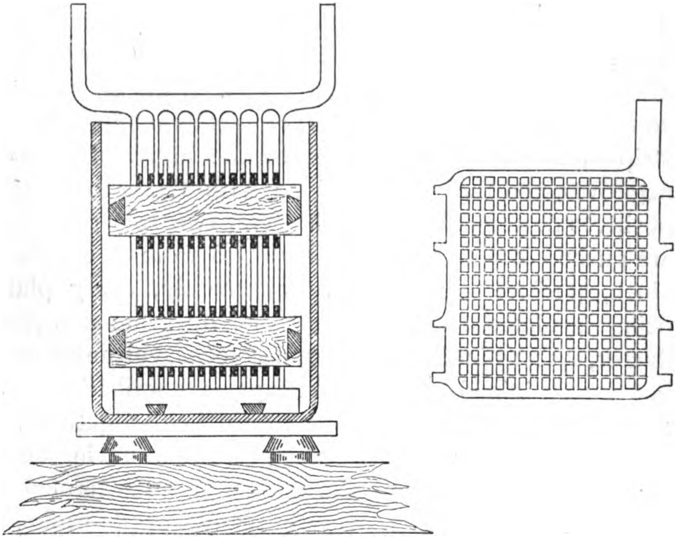
to make it a practical one; in fact, those now so largely used are but improved Faure cells.

The chief aim of all improvements in the lead plate type is to make the plates porous, yet strong, so as to offer as large a surface as possible to the electrolyte.

The second type may be termed "pasted plates." Here the perforated or honeycombed plates are filled

with paste, red lead mixed with sulphuric acid for the positive paste, the mixture forming lead sulphate, and the negative paste is made with litharge. In this type of cell, as well as in those of the Planté kind, dilute sulphuric acid is employed for the electrolyte.

The chemical action is the same for both types of



FIGS. 2 AND 3.—E. P. CELL AND PLATE. THE AUTHOR'S METHOD.

plates, and may be explained generally by saying that when the cells are charged, more oxygen exists in the positive plates, and hydrogen in the negatives, than when discharged. Without giving a detailed account of their manufacture, a few words on this subject may prove of interest.

First let us take those of the Planté type. There are still many makers of this kind of cell, each of whom have a different method of rendering the lead plates porous. Some cast them porous to start with, others build them up of lead ribbon, and most treat the plates with nitric acid before placing them in the cells. In all cases the same end is in view, viz., porosity. The positive and negative plates are identical at the start. They have luggs either cast on them or put on afterwards to project above the level of the electrolyte, so that the plate itself may be completely immersed. A strip of lead is then soldered to the luggs of all the negatives, and the same is done with those to be the positives destined for one cell. The two sets of plates are pushed into one another so as to form a compact block, positive and negative alternately, every plate being insulated from the next one by some non-conductor, such as india-rubber bands, blocks, vulcanite, etc., but remain joined by the lead strips as described above. Such a block of plates is then firmly held together by rubber bands, or a wooden frame, the wood having been boiled in parafine, and the whole is now termed a "section." These sections are ready for "forming." This process consists in passing an electric current for a long period through the cell, a large number being coupled together in series to undergo the process. The result is that, notwithstanding both positive and negative plates start identical, after a time they alter their chemical composition, and soon become capable of retaining a charge, meaning, scientifically, that a good primary

battery is obtained with reversible properties. The chief drawback to this type of cell is that frequent reversals are necessary to obtain good storage capacity, and when the maximum is reached the plates become rotten. It therefore takes a long time before the cells have much capacity, and reversals are troublesome as well as expensive. A "reversal" is accomplished by completely discharging the cells through a resistance, then charge again the reverse way, and to complete the process another discharge must be given, and a recharge in the original direction. Such cells are also very heavy for their storage capacity. The only point in their favour is that a very large charging current or rapid discharge does not appear to injure the plates, which is the case with the pasted type. Such a battery is therefore very suitable for regulating the light, and for short heavy discharges, but undesirable for storage, although a few authorities say that such cells have proved successful in their hands.

The second type is unquestionably the most useful, notwithstanding the extra care and attention required, and it is these which are almost universally in use at the present day. All which follows in this book regarding cells applies almost exclusively to this type, for there is little to say in respect to the other on account of their simplicity, but of course all the general phenomena during charging and discharging are the same for both types of cell.

The pasted plate is made in many ways, but virtually they all turn round one point, which is to produce a

leaden or some other support carrying paste. The E.P.S. (Electrical Power Storage Co.) and the E.P. (Elwell Parker) plates are identical, excepting in the details described further on, and consist of lead, or an alloy of lead, cast into plates covered with small square holes, pyramidical in form, with their bases on the surface of the plate, minute-glass shape in section, with a lugg to attach the connecting strip of lead to when built up into sections. Both these firms now use an alloy of lead to obtain a better plate, or grid, as it is called, the alloy being far stronger than the lead alone. Both makers used to make the holes in the positive and negative plates of the same size, but now the E.P. plates have the holes larger in the positives. The plates intended for positives are pasted with red lead and sulphuric acid, and those to be negatives with litharge and sulphuric acid; in this latter case water would answer the purpose but the paste would not be so coherent.

They are now built up into sections by soldering the luggs of a number of positives to a strip of lead. A number of negatives are treated in the same way. These two sets of plates are pushed into one another, so that positive and negative alternate, and every plate is insulated from the next one, in the E.P.S. make either by blocks of rubber having been inserted into some of the holes on each negative plate, which was the old way, or as now by two or more rings of rubber put round the negatives vertically before being placed between the positives; a plate of thick glass is then placed at each end of the section, and two stout rubber bands are made to

encircle the whole, one near the top and one at the bottom of the section horizontally. The number of negative plates always exceeds the positives by one, so that a negative is seen at each end; of the remaining ones the edges only are in sight, the plates being about a quarter of an inch apart, positive and negative alternately. There is no connection between the positives except through the leaden strip at the end of the luggs, this being left long enough to join to the next cell, and the ends of the luggs with the strip always remain above the liquid in the cell. These remarks also apply to the negatives. The E.P.S. section is now ready for forming. These cells are shown in figure 1.

The variations in the E. P. type are as follows (see figures 2 and 3):—The old method was to use rubber rings to separate the plates in the same way as in the modern E. P. S. In fact, the latter makers deserted the rubber blocks for rings, long after their adoption by Messrs. Elwell Parker; and this also applies to the grids of alloy. The sections of the latter firm are now held together by strong wooden frames, the wood having been well boiled in parafine. The squares (the holes appear this shape on the surface of the plate) on the positives are larger than on the negatives; the plates are also somewhat thinner. Messrs. Elwell Parker's improved sections are now built up upon a plan patented by the author, whereby rubber blocks and rings are dispensed with. It consists in casting some small luggs on the edges of the plates at suitable distances, these rest on the bars of the wooden frame, and are kept apart by ebonite

pins, which are fixed in holes in the bars of the frame. By this method, of which there are numerous variations, all tending to the same end, there is no need to place anything between the plates, and as the luggs are outside them, the intervals are quite clear; an ebonite rod is pushed between each plate, in case of need, but this is not absolutely necessary. There are luggs, as usual, for connecting the plates together, but instead of soldering or burning on a strip of lead, the equivalent is done by casting the strip on the luggs, which is more convenient and looks neater. The pasting is nearly the same as for the E. P. S. plates, and in both the electrolyte consists of dilute sulphuric acid.

In all cases the sections rest on wooden frames or blocks, so that they shall not touch the bottom of the pots. The cells are now connected in series, and a current passed through them for a long period, causing the paste on the positives to become converted into lead dioxide; but the conversion is not complete, as will be explained later, and the paste on the negatives becomes partially reduced to finely divided lead. This process having been gone through, the sections are said to be "formed," *i.e.*, ready for use. It will be shown in a future chapter that the whole process of charging and discharging is a "sulphating" one, and where the word "sulphating" is employed, the meaning is that higher sulphates have been formed on the positive plates, which cannot be reduced, or only with difficulty; so this expression is used as short for "deleterious sulphating." In the same way the term "fully charged" must be

taken to imply "sufficiently charged for practical purposes."

The positives may be distinguished from the negatives by their colour, which is plum colour; some call it chocolate, red, dark red, and dark coloured. The negatives have a yellowish tint on the surface, and pale slate colour at the edges.

There is yet another kind of positive plate which deserves our attention, and is said to be the "coming plate," but on this point reserve is necessary, since they have not been in practical use yet, and the opportunity of proving themselves against the wear and tear of time is yet to come. They are made of solid peroxide without a leaden support, and in their present form, Mr. Fitzgerald may be regarded as the inventor. He gives the material the name of lithanode, but there is not the slightest reason for calling this well-known substance by a new name.

By many these plates are termed "Union plates," after the Company, which professes to have the monopoly to make them, and is supposed to do so, for at the present time they are not in the market. It is very probable that these lithanode plates will prove successful either in their present form, or with some modifications, for reasons which will be evident from the considerations given in a later chapter.

No matter what cells are used, care and attention are always necessary; at the same time any intelligent man started by a competent teacher will soon learn what should be done on all occasions which may arise, and

before long it would appear that the accumulator takes care of itself.

Every cell with lead plates, no matter of what form, gives two volts or thereabouts ; thus one cell is useless for lighting purposes, because 50, 60, 80, and 100 volts are the most common pressures required for practical purposes, the lower pressures for small installations of, say, 30 to 50 16-candle power lamps, and beyond this number the higher pressures are employed. Thus, an accumulator generally consists of 25 to 50 cells, or 27 to 54, so as to allow a few extra for reserve.

The cells are connected to one another by joining the leaden strip connecting the positive plates in one cell to the strip connecting the negatives in the next one, and so on. They are then said to be connected in series. The strips may be joined by solder, by bolts and nuts, or by clamps.

Cells can also be connected in parallel, whereby two or more may be made to act as a larger one of twice or more times the capacity of the single one (if all of equal size), but the E. M. F. will be that of one cell only. Again, they may be connected up in parallel and series. For instance, if in an installation requiring 50 volts, double the capacity of single cells is required with the same pressure, and larger ones are not to be employed, then if 27 cells were first installed, these must be increased to 54 and coupled two and two. This is effected thus: the positives and negatives of two cells are joined together, positive to positive and negative to negative, these are then treated as one cell, the positive

at one end being joined to the negative of the next couple, and so on. It is clear that far more complex arrangements are possible, such as cells in series, placed in parallel, and then again placed in series. All combinations have their uses under special conditions.

CHAPTER II.

SETTING UP THE CELLS AND THE ACCUMULATOR HOUSE.

ON their arrival, the cells should immediately be unpacked and got ready for the plates, which do not improve by standing exposed to the air.

Strong shelves should have been prepared for their reception, and small boards on which to place each cell. These boards in turn stand upon porcelaine or glass insulators, which may be filled with oil, in certain patterns, to insure better insulation. The glass pots—for these are best for stationary work—should be placed upon the boards with the insulators under them, along the shelves, leaving about an inch between cell and cell, but they must not touch. The object of the boards is to prevent the insulators from cracking the cell by an unequal distribution of the weight. The shelves and cell boards are best varnished, for insulation as well as for cleanliness sake. The edge of each cell should be painted round the top edge, for the breadth of an inch, with parafine wax, which prevents the liquid creeping

over the top, rendering the outside wet, and impairing the insulation. It is of the highest importance that every cell should be perfectly insulated to avoid waste by leakage. The room should have nothing in it to spoil by contact with acid fumes, and good ventilation is essential for the health of the attendant, otherwise it will be almost impossible to enter the apartment during charging hours. The next step is to unpack the plates with care. These arrive in crates or boxes, one section in each. They must not be handled roughly. The section must be taken out without disturbing a single plate, and if packed with straw, every particle of packing must be removed; and see that no chips or bits of paste stick between the plates. The spaces between the plates must be absolutely clear. Future success, in a great measure, depends on the way in which the sections have been unpacked and freed from rubbish. At this stage it is supposed that the cells have been cleaned, the edges waxed, placed in position upon the shelves, and that the plates have all been unpacked. The next step is to put the sections in the pots. In a well-appointed accumulator house this is simple enough, and the arrangements best adapted to this end will be described, but we will first suppose that luxuries do not exist.

Remove the first cell from the shelf, and place it upon a piece of board on the ground. This board should be rather narrower than the cell, to facilitate lifting it when the plates are in. The support for the section is first put in the pot, consisting of a skeleton frame of wood, in most instances. Be careful

to put it in the right way; the thicker sides of the frame must carry the plates, and therefore their edges rest upon them; these thicker sides also project above the level of the frame, so that the flat side rests on the bottom. Pieces of parafined wood must be placed under the frame if it does not take a level bearing on the bottom. This is necessary to avoid the weight of the section from breaking the glass. Now lift a section clear of the cell, and lower it gently till it reaches the bottom, and rests fairly upon the frame, seeing that the plates have not shifted, and are quite straight and central in the cell. The section should not touch the sides, but have a small clear space all round. Generally the mouth of the pot is square, but if not, allow the greater space to exist between the edges of the plates and the sides of the vessel, unless the dimensions of the sections are such as not to admit of their being placed in this manner, this allows room for the acidometer, which is shown in figure 4.

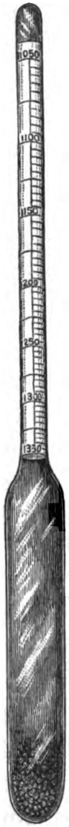


FIG. 4.—ACIDOMETER.

To lift the sections from the packing cases, and again into the cells, hooks will be found the most convenient. Two men are required for the purpose, the sections being very heavy. The hooks consist of a piece of iron wire about No. 1 S. W. G., bent to the shape

of the letter **U**, the free extremities being again bent into hooks, each half a circle of two inches diameter. The plane in which the hooks are turned are such that they are not seen when the whole is viewed as a letter **U**. The rounded corners of the **U** are squared, a piece of half-inch iron gas tube having first been slipped on to avoid cutting the hands whilst lifting. When employed to lift the plates, one pair of hooks are applied to the positive lead strip, and one pair to the negative. In this way two persons can lift small or large sections with ease, and lower them into the cells gently without risk of breakage. Each cell completed is put back in its place upon the shelves.

To effect this in the best way, put the cell which is still upon the floor on one of the cell boards, which rest upon the insulators, and lift the board with the cell together into position. For high shelves a staging is necessary, on account of the great weight to be lifted. The floor should be of vitrified blue brick, diamond pattern, and falling all ways to a drain. This permits it to be easily washed by flooding with water, and the pattern allows it to be dry at all times under foot. Wooden floors rot very soon by acid spillings and the spray. When all the cells are in position they are ready for connecting. The last chapter describes the methods of doing this. Solder, bolts and nuts, or clamps, are used according to circumstances. Often solder is employed in all cases, but this is not essential if there is a good surface of the lead strip of one cell in contact with that of the next, and these

surfaces have been well cleaned. The ends of the lead strips are turned up, so that those of two adjoining cells with the junction appear like this $\perp$. If the junctions are not in thorough contact they will become hot when a current is flowing. It is desirable to make the connections so as to include as little lead strip in the circuit as possible, thus diminishing resistance and waste. The insulators may be steeped in parafine wax, which has the advantage of increasing their insulating properties, and permits the boards on which the cells stand to be moved with great ease, and in practice this is convenient for placing them straight. The room should be cool and shady, for sunlight falling upon the cells is a constant source of breakage. Evaporation also is kept to a minimum. When possible it is a good plan to have a passage behind the shelves wide enough for a man tc pass. Thus the edges of the plates can be viewed from each side. The space between shelf and shelf should be such that the cells may be easily looked into from above. If the battery is erected as mentioned, the edges of the plates will always face the person inspecting them. Brass or gunmetal clamps may be kept clean by brushing them over with parafine wax, melted in a metal or glue pot, after screwing up.

All the difficulties attendant on lifting heavy cells in confined spaces are got over by erecting an overhead traveller with dynamic pulley blocks, on which hangs a suitable cradle, with an adjustable counterpoise; by this means a cell may be placed upon a shelf, or removed in a minute, no matter how

heavy it may be. Such a cradle is shown in the frontispiece. The movable counterpoise enables the cradle to remain level, whether a cell is on or off of it, and by this method the point of suspension is not over the cell, which would render its service useless in the case of shelves.

Those who put up batteries are liable to certain disadvantages, such as destruction of clothing and sore hands. There is a cure for this. The boots should be painted with parafine wax, mixed with an equal quantity of beeswax, this mixture being pliable. An apron of sacking, backed with common flannel, should be worn. The clothing should be of woollen material, sewn with worsted, not cotton. Wool, in fact, is scarcely affected by acid. The shirt should be dipped in a solution of strong washing soda, and rough dried. With these precautions the clothing is fairly well protected. A bottle of ammonia fortis ought to be kept in the accumulator house in case of an accidental splash of acid on clothes liable to injury. The wetted stopper of the bottle applied to the place at once neutralises the acid, and avoids a hole being burnt in the material.

When at work a pail of water rendered strongly alkaline with washing soda may be at hand, in which occasionally to dip the hands, to prevent the skin from smarting under the action of the acid.

The cells are now supposed to be in position and connected up, all that remains to be done is to fill the pots with liquid, connect the dynamo wires, and start charging. It is usual to paint the positive strips

of the sections red, and the negative strips black or unpainted, so that it is easy to distinguish the positives at a glance. The end cells of the battery have each a free strip quite disconnected, one end being a positive one, and the other a negative, if no mistake has been made in connecting up. The positive end of the accumulator is joined to the positive cable from the dynamo, and the negative to the negative. The dynamo must be of the direct current type and shunt wound. It is of importance that the reverse connections are not made. Therefore nothing is taken for granted, the dynamo wires must be tested. Take a vessel of any kind—a jam pot answers the purpose—and two pieces of sheet lead about one inch wide and six inches long. Nail these lead strips to a piece of wood one inch square in section and four inches long, so that the lead projects at one end. The nails must not meet in the centre of the wood.

This latter is best shellac varnished. By means of common clamps, such as are used for laboratory primary cells, join one lead plate to each dynamo cable, putting an ordinary 16 c.p. lamp in the circuit to check too much current flowing. The dynamo cables are too large for these connections, so a piece of No. 16 or 18 S.W.G. wire may be attached to the end of each cable to continue to the testing cell. Place in the pot dilute sulphuric acid about one part acid to ten of water. Scrape the mounted lead pieces clean, place them in the liquid and start the dynamo at a moderate speed. In a few minutes examine the strips of lead; one will

have become brown and the other grey; trace which dynamo cable is joined to the lead which is brown. This is the positive cable, and should have its end painted with red shellac varnish for future distinction. The test concluded, and the dynamo stopped, the cable marked red is joined to the positive end of the battery by solder or a suitable clamp, and the other cable is fixed to the negative end. Since it is imperative to start charging directly the cells have been filled with liquid, and to continue the process till the liquid sparkles sharply, or boils as it is termed, it is better not to fill up till all is ready. The strength of the acid solution depends upon how far the process of forming has been carried, and the better formed the more is it to the advantage of the customer, for otherwise a long charging has to be given before any real storage commences.

Doctors differ as to what strength the solution should be. Acid too weak or too strong destroys the plates. The E.P.S. cells have the sulphuric acid mixed with water till the s.g. is 1·170, and when the cells are charged the s.g. rises to 1·200 or 1·210. The E.P. cells have acid put in s.g. 1·130, and it runs up to 1·180 or 1·190. It is best to purchase the acid ready diluted. Pour sufficient into each cell to cover the plates completely and to within half an inch of the top edge of the cell. After filling, the s.g. of the liquid falls considerably, but rises again on charging. It is a good plan to place an acidometer in every cell; by this means the specific gravity of the liquid in every cell can be taken and the variations noted during the charging hours. Glass slips

are now placed over the top of each cell which are curved, the convexity facing the liquid. Any spray driven off is collected on the glass and runs back into the cell, tending to keep the level of the liquid constant, and the room free from acid fumes.

A water tap and sink should exist in every accumulator house. The battery is now ready to start charging, which should be commenced without delay.

Before proceeding to the next chapter a description of the Broomhill accumulator house will not be out of place, having been erected as a model. It has now been completed more than a year, and its practical convenience has been amply tested and proved. The frontispiece is a representation of the room.

The room is about twenty-eight feet long by eleven feet wide and thirteen high. The roof is flat, with a dome skylight in centre four feet diameter, and the north end of the roof is a lean-to light the whole width of room by five feet, and faces north. This arrangement never allows the direct sunlight to fall on the glass cells, which is a constant source of their breaking. In the south wall there is a large window, opening like a French casement, for ventilation, but shrubs are planted outside to keep off the sun's rays. There are ventilators in the roof besides, and two doors at the north end facing east and west, to admit air from outside when desired, and a door in the north wall leads to the engine house. The shelves run north and south, and are two feet from either wall, leaving a good space between the cells and the wall for a man to pass and work. The two

rows of shelves have three tiers in each, with a broad alley down the centre. The shelves are two and a half inches thick and nine inches broad, and drop on bearers screwed and let in to standards, six on each side, two inches thick, eight inches wide, and about eight feet high; the tops are tenoned into pieces of wood which bridge over the two-foot pathway, and are let into the wall; there is a piece of timber bolted through each wall running north and south, and these cross-pieces are let into and screwed to these also: thus there is no possibility of the shelves falling inwards or outwards. The bottoms of the standards rest on a chequered blue vitrified brick floor laid on concrete. The shelves, being broader than the standards, have the ends mortised in such a way that, though loose on their bearers, it is not possible to shift them when laid in their places. The distance between them is sufficient to allow the cells to stand, with twelve or fourteen inches to spare, to enable an easy examination of the plates to be made from above. There are zinc plates nailed on the edges of the shelves, bearing numbers in black on a white ground, to identify each cell. The floor is slightly inclined, and, being chequered, is easily washed down without remaining wet under foot, with a grating at one end to carry off the water. There is also a sink and water tap in the room, and a small place adjoining (some six feet square) for an acid tank and the other requirements strictly necessary for an accumulator. The walls are cemented, the ceiling match-boarded, and all woodwork sized and twice varnished. Two fifty-candle-power lamps in the

ceiling light the room, the switches being on the post of the entrance door; also a large Wenham gas burner exists, should it ever be required; a gas soldering apparatus; and a portable lead burning arrangement devised by Mr. Stephen Holman, of Messrs. Tangye. All windows and skylights are barred, to keep out intruders of a badly-disposed kind. The design of the shelf-racks is such, that eight feet after leaving the floor all is clear, the lamps even being above ceiling line. This space allows an overhead half-ton traveller to run north and south, the rails being laid upon timbers borne by the cross-pieces between shelf standards and wall. There is a special cradle with adjustable counterpoise so made that the cells may be lifted with perfect ease, without requiring the point of suspension to be over a cell. The pulley blocks and traveller were made by Messrs. Tangye, and the cradle devised at Broomhill. So successful is this arrangement that one man can move a cell, filled with liquid, from one point to another, and to any level, in a moment. Two men are found to be more convenient for rapidity sake—one to look after the cell, and one to move the traveller and work the blocks.

Each set of shelves holds 54 cells of 23 plates, 108 in all, one set of 54 being E.P.S., and the other 54 of E.P. make. At every fourth cell there comes an upright standard, and between every two a loose prop between shelf and shelf to prevent any tendency of the wood to bend. The bottom shelf is six inches from the ground; at the south end the shelves are returned sufficiently for a cell on each row, should a few more ever be required,

or a few cells inserted for experimenting upon, leaving a passage through to the south window. All cells rest on Elwell-Parker insulators, and are connected one to another by special cast iron and gun metal couplers, each of which has an attachment to take a cable, which is most useful in case of need and for experiment.

The picture shows all improvements, also a cell suspended in the cradle, to illustrate the method of using it.

One hundred and eight cells can be unpacked, set up and started charging in ten hours by six men, which probably exceeds the fastest work on record.

CHAPTER III.

CHARGING.

THE first charge differs in some respects from charging in the general way. There should be a steady run of thirty hours without stoppage if possible, or not less than ten hours a day during three days, for the usual size of cells, when the liquid in them will commence to boil, having a milky appearance due to the quantity of gas bubbling through the fluid, and its s.g. will rise to about 1·200 by the acidometer. By the word "boil" it does not mean rise in temperature. The charging must be continued till every cell appears to boil in an equal degree. The current should be kept well within the maximum allowed. For some weeks probably there will be a difficulty in getting the cells in an equal state, and long charging alone will put this right. Over-charging does no harm whatever, unless the current is too great. If one particular cell here or there will not boil it is best disconnected from the circuit during hours of discharge, to be re-established when charging is started. Should this fail in the result sought for, the plates must be examined. Every cell should be

separately tested for E.M.F., which should not be less than 2 volts, if under 1·9 volts the cell has been discharged as low as it is safe to do. When nearly charged, 2·1 to 2·2 volts per cell will be registered. At the conclusion of a charge, for a short period of ten to fifteen minutes, each cell gives as much as 2·3 to 2·5 volts, then the E.M.F. drops to near the normal, and after a slight discharge the usual E.M.F. will average 2 volts per cell as near as possible. These tests are taken on open circuit, that is when the cells are not charging or discharging.

There are two convenient ways of ascertaining the E.M.F. of individual cells, both made by the E.P.S. Co. One consists of a 2-volt lamp mounted on a small piece of ebonite having the point tipped with brass, which is in electrical connection with one loop of the lamp. The other loop is continued to a terminal to which a piece of wire is attached, ending in a brass cap with a point on it, which is used as a protector for the lamp when out of use. It is necessary, when testing, to place the brass point on the ebonite rod on one strip of the plates in the cell, and the pointed cap at the end of the wire on the other strip; the plates are now short-circuited through the lamp, and by its brightness the condition of the cell may approximately be ascertained. The other instrument is a more scientific one, and consists of a little voltmeter very portable and well protected (see plate 5), which registers from 2 to 2·5 volts on a very open scale, and is dead-beat. Two wires leave this apparatus and are attached to a cylindrical

wooden rod having roughened brass tubes fixed upon it at each end, one wire being connected to each piece of tube, and which are insulated from one another. When used, the rod is simply laid across the cell with one hand, the length of the rod being suitable for this purpose, whilst the voltmeter is held in the other one and observed, each brass tube resting upon a lead strip.

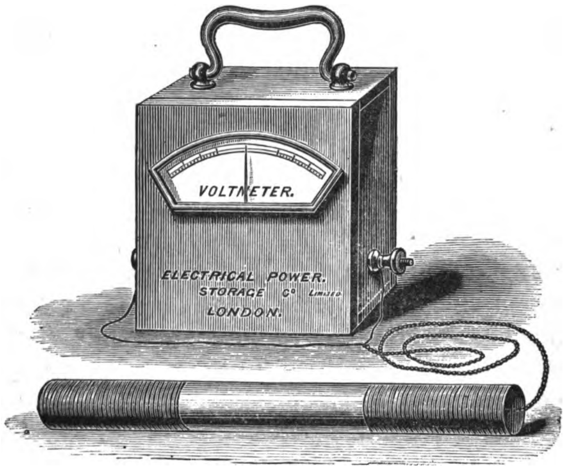


FIG. 5.—E. P. S. CELL TESTER.

Failing a good connection between the tubes on the rod and the lead strips, it is only necessary to move the rod file fashion, when the roughness on the tubes will clean the lead, establishing good contact.

Since the sizes of the E.P.S. and E.P. plates are the same, and all conditions under which they act are similar, and probably these remarks will also apply to

the Lithanode plates, the charging rates may be regarded as general to all plates of the pasted type. Several sizes of plates are made, but for electric lighting work in permanent installations those termed **L** plates by the E.P.S. Company are mostly used. Those of the E.P. make are also of the same size. It is found best to use cells with 15, 23, or 31 plates in each. Those containing 31 are not much used on account of their weight. It is not too much to say that the 15 and 23 plate cells of the E.P.S. or E.P. make are in almost universal use for stationary work. The proper charging rate is 5·3 ampères per square foot of positive plate. Thus in a 15-plate cell, which contains 7 positives, 20 to 22 ampères should not be exceeded for charging; in the 23-plate size, with 11 positives, 33 ampères is the maximum charging current. For the **L** size of plate the rate may be expressed by saying 3 ampères per positive plate. If a much larger current is passed the cells boil as if they were fully charged, showing that the surface of the plates is insufficient for the current to act upon, and the excess of current does its work by simply decomposing the water of the electrolyte, creating volumes of gas, and heating the liquid. Independently of this waste the plates become injured.

If the E.M.F. of the charging current is 10 per cent. above that of the accumulator, it will be found that about the proper amount will flow. The exceptions are at the commencement of charging, and a short time before the cells boil. The E.M.F. of the charging current must be lower at the start, and greater

at the end of the run, to keep the current constant, for the E.M.F. of the cells is low in the first case and high in the latter. Where no provision exists for keeping the charging current constant, it will be found that if at starting it is normal, then as charging proceeds the current will grow less and less; consequently the time required to run in such cases is very much longer than when it can be kept constant. If the charging current is very small, say one-tenth of the maximum, then, however long the run, the cells do not appear to charge, unless they are in perfect order, and the insulation exceedingly good, and this is rarely the case. So much for the practical side of the charging question. The result of charging is to convert the $PbSO_4$ on the positive plates to PbO_2, which change is thus effected: SO_4 goes to the electrolyte in exchange for O, the liberated H_2 of the water (H_2O) joining with the SO_4 form H_2SO_4; the next action is another atom of O joining the PbO, making PbO_2, and the liberated H_2 of the H_2O going to the PbO of the negative plate forms $Pb+H_2O$, these chemical actions may be thus represented:—

	Positive.	Electrolyte.	Negative.
1	$PbSO_4$	$H_2SO_4+H_2O$	PbO
2	PbO	$H_2SO_4+H_2O$	PbO
3	PbO_2	$H_2SO_4+H_2O$	Pb

We start with No. 1. In No. 2, a molecule of water has been removed, and one of H_2SO_4 added, the strength of the acid solution has been increased, this

remains unaltered in No. 3. Hence we see why the s.g. of the electrolyte increases as the charging advances. It will also be noticed that the H_2SO_4 originally put in appears to play no part whatever, beyond making the water a good conductor, yet if no H_2SO_4 is added in the first instance, the chemical actions are not quite the same, and the plates soon get injured by secondary actions, giving at the same time a lower E.M.F.

The chemical actions are probably far more complex than those given above, but generally and diagramatically the explanation given is fairly correct.

There is, however, an additional action which proceeds during charging, for gas is given off at all periods of the charge, first off the positives only, and later off the negatives also. This tends to prove that water is being decomposed, the O of which does not unite with the paste of the positives, and that H is absorbed or goes into chemical combination with negatives, and finally, when the end of the charging approaches and the negatives can absorb no more gas, H is given off from these plates.

There is far greater loss with cells than is generally supposed; notwithstanding that many eminent men have shown great efficiency in laboratory tests, but for practical purposes such tests are worthless, and no one is recommended to expect more than 65 to 70 per cent. of efficiency in the long run. These are about the figures obtained from six accumulators over long periods.

There must be the loss in getting current through the

battery in the first instance, which is about 10 per cent.; then power is required to get it out, if such an expression may be allowed. There is loss through leakage, local action, through cells being in bad order at times, and from many other causes, which do not exist in the usual laboratory tests.

If the strength of the acid solution is above 1.700, bad sulphating rapidly ensues with great loss of capacity, although giving a good E.M.F. The level of the liquid in the cells must be kept constant; to effect this, the first few additions of fluid should be H_2SO_4 s.g. 1.150 or 1.170, after this only water, unless it is found on completion of the charge that the acid is below the normal strength, in which case fill a few times, when necessary, with acid solution as just mentioned.

It is found that when the cells are fully charged, only a very small proportion of the $PbSO_4$ has been converted into PbO_2. Whether this is due to the blocking up of the material from some cause or other, or not, it is difficult to say. Mr. Swinburne in "The Electrician," of July 10th, 1885, writes. "Some years ago, when I made a large number of experiments on batteries, I found in no case more than six or seven per cent. of the coating is used, even when the cell is completely run down. The expansion of the peroxide of lead in becoming sulphate perhaps blocks the coating up." By experiments conducted by Dr. Gladstone, and the late Mr. Tribe, 32 per cent. of the total paste was found to be active material. Any way we may look forward to improvements in cells which will increase their capacity many fold. Claims

are put forth for the Lithanode plates regarding their increased capacity.

The following tables are copied from an able paper read before the Society of Telegraph Engineers and Electricians on March 10th, 1887, by Mr. Desmond Fitz-Gerald and they may prove of interest:—

TABLE I.

STORAGE CAPACITY OF VARIOUS SECONDARY CELLS.

Name of Cell.	Per lb. of Pb.		Per kilo. of Pb.		Authority.
	Foot lbs.	Watt hours.	Kilogram-mètres.	Watt hours.	
Planté	12,000	4·52	3,664	10	
Faure	18,000	6·78	5,495	15	
E.P.S. L plates ...	48,000 (?)	18·09 (?)	14,600 (?)	39·8 (?)	Howard.
" R " ...	36,080	13·6	11,010	—	(?) Hospitalier.
" S nominal 22 lb. cell ...	31,800	12	9,540	26	Fitz-Gerald.
Elwell-Parker (old form)	6,633	2·5	2,018	5·5	Prospectus.
Lithanode battery (old form) ...	39,798	15	12,110	33	Fitz-Gerald.
Lithanode battery "Union" cell...	47,170	17·8	14,671	39·16	G. Forbes.

TABLE II.

WEIGHT PER HORSE-POWER-HOUR CAPACITY OF VARIOUS SECONDARY BATTERIES.

Name of Battery.	Elements only.		Cell complete.		Authority.
	Lbs.	Kilos.	Lbs.	Kilos.	
Planté	...	...	396	180	Reynier.
Faure	...	...	88	40	Faure.
	...	...	165	75	Sir W. Thomson.
,, (old model)...	...	...	198	90	Reynier.
,, (new model)	...	...	134	61	
E.P.S. L plates ...	...	...	133	60·4	Prospectus.
	...	...	110	50	Reckenzaun.
,, S ,, ...	66	30	135	61·3	Fitz-Gerald.
Reynier Zinc posve.	50·6	23	117·5	53·4	R. Tamine.
Reynier Planté form	105	47·6	...	...	*Idem.*
Lithanode battery (old form) ...	42	19·1	76	34·5	Fitz-Gerald.
Lithanode battery "Union" cell ...	42	19	70	31·5	G. Forbes.

Mr. Fitz-Gerald doubts the accuracy of Mr. Howard's results either from error or from the methods he employed.

We have seen that as charging proceeds the s.g. of

the acid becomes denser, and the E.M.F. rises. Let us now examine this question. Water is a very bad conductor, and H_2SO_4 a good one, therefore the weaker the acid, the worse are the conducting qualities. Kohlrauch gives the following table for the specific conductivities of an electrolyte made with water and sulphuric acid.

s.g. at 18°c.	Conductivity at 18°c	per cent. in sol $H_2\ SO_4$
1.1036	5084	15
1.1414	6108	20
1.1807	6710	25

The arrow heads show direction of increasing conductivity.

It will be observed that since the solution is put into the cells at 1.130 or 1.170, the mixture is approximately a 20 per cent. solution, or one part strong H_2SO_4 to four parts water; and again, since the s.g. at the end of a charge rises to 1.180 or 1.200, the solution is then about one of 25 per cent., and its conductivity is some 10 per cent. better.

Great care is necessary in mixing the solution, a large vessel must be employed, by preference of lead with burnt seams, and the acid must be poured into the water slowly, and cautiously, because the temperature of the liquid rises to a high point, and splashes might do serious injury, even produce blindness. The water must never be added to the acid. It is always safest to obtain the solution ready mixed.

A well-charged cell is found to have about half the resistance of a discharged one. This is due partly to the difference in the conductivity of the electrolyte as

explained, and partly to the surface of the plates being in a better conducting state when charged. The sulphate of lead is a poor conductor, and when higher sulphates form, which often is the case when discharged, an enamel of a very bad conductor is formed in patches, diminishing the active surface of the plates, and very difficult to reduce. By active surface is meant, that surface upon which the current can do useful work.

Certain advantages exist from the fact that the resistance of the cells grows less as charging proceeds. Were this not the case, for a Dynamo giving constant E.M.F. for all currents within its capacity, it is evident that the charging current would rapidly grow less as the charge approaches the end. It does diminish, but not in any great degree, although the counter E.M.F. may have risen as much as 15 per cent.

The great necessity for keeping all the connecting strips of low resistance and short, the junctions clean, and the leads short and large, may be illustrated by an example. Suppose a set of fifty cells, with a normal charging current of thirty ampères, which has an E.M.F. of 110 volts, then since the fifty cells themselves give 100 volts, this acts as counter E.M.F., *i.e.*, in opposition to the charging current; thus ten volts is the true pressure which passes the thirty ampères through the accumulator, so the total resistance for cells, leads, and connections is about one-third ohm. This is much increased if the connections are not clean or the cells not placed close together to shorten the lead connecting strips as much as possible. It will also be observed that if the charging

current were raised to say 112 volts, a much larger current would flow, since the forcing power would be twenty per cent. greater. It is also evident that the rise of E.M.F. in the cells, as charging advances, must materially reduce the effective margin of pressure, notwithstanding the lower resistance of the cell. The methods of regulating charging currents will be dealt with elsewhere.

The next point to consider is why boiling occurs. It must be clear that as the surface of the positive plates becomes converted into lead peroxide, the material to be acted upon by the current grows less and less, the plates become virtually smaller, and consequently the current becomes too large, resulting in decomposing the water of the electolyte, and often warming it considerably.

However, in practice it would not pay to gradually reduce the current as the charge advances, so it is neglected; but it can be experimentally shown that by doing this boiling never occurs, and hundreds of ampère hours may actually be added beyond what is accomplished in the usual way before boiling commences. In fact, an infinite charge (in point of time, but finite in quantity) might be given if the current is continually reduced to suit the lessening active surface of the positive, since the series is infinite. Boiling does no harm unless the paste is loose, when much will be removed by the agitation of the liquid. Frequent prolonged overcharging with currents about 30 per cent. below maximum is the only way to reduce the higher sulphates of lead which are apt to form when the cells

are allowed to run too low. Such sulphates are most obstinate to reduce, and the least speck remaining indicates more will form, almost like a growth of mould, so when observed, overcharging must be resorted to, when it falls off in scales or powder, the healthy oxide forming beneath it, to which it will not adhere.

If, when the cells boil, the charging is stopped for half an hour or more, and the process re-started, it will be found that boiling will not recommence for some time, and this process may be repeated again and again. When boiling takes place we obtain a kind of gas battery, both positive and negative plates being covered with a layer of gas. On stopping, this escapes or becomes partly absorbed, so the plates are once more exposed for a short charge before the phenomenon occurs again.

If too large a charging current is used for the area of the plates, buckling is likely to ensue, and very rapidly if any bad sulphate is present on the positives; and short circuiting due to plates touching one another in the liquid soon takes place. Buckling is due to unequal expansion of the plate, and even under the best treatment buckling takes place if the makers have not given them a proper form. The paste expands on discharge, and *vice versâ*, so it is absolutely necessary that such expansion and contraction shall be symmetrical over the whole surface. After a time these continual changes loosen the paste from their supports, but repasting can then be resorted to if the grids are uninjured. Some years may elapse before this becomes necessary under judicious treatment, and applies chiefly to the positive plates.

The troubles which can arise with the negatives will be commented on later. Buckling may also come from other causes, which belong to the next chapter.

It might be supposed from the above that when boiling starts, due to the current at this time being too great for the work to be done on the plates, risk of buckling the positives should occur. However, this is not so, because the case is not the same as when the surface of the plates is actually smaller, there is still a large surface upon which the current can do its work, but instead of forming PbO_2, it decomposes the water of the electrolyte. It is often necessary to give prolonged charges to remove any white sulphate that may form. In such cases the current should be reduced, say to two-thirds or half the maximum, otherwise much paste may be removed.

From time to time water must be added to the cells to keep the plates well covered. It has already been explained that for the first few times acid solution s.g. 1·130 or 1·150 should be added, but if at any time the s.g. or the electrolyte falls below the normal, then the acid solution is again added to keep up the level until the normal is again reached. It is therefore most desirable to place an acidometer in every cell, to indicate not only the s.g. of the liquid, but by its rise and fall a fair estimate of the charge can be arrived at. For instance, if the acidometer in a cell refuses to rise, then a careful examination must be made, as something is at fault; most probably two plates are touching. Again, if the apparatus rises more slowly in one cell than in others, then a

leakage is taking place in that cell, probably due to one or more pieces of paste sticking between two or more of the plates. It is of the greatest importance to keep the charging current within the maximum permissible at starting by means to be described.

The plates in cells, no matter of what kind, should be so arranged that the resistance from all parts of one plate to every portion of the adjoining one shall be equal, otherwise buckling will take place. The plates should also be so arranged that they cannot shift.

There is no better test for ascertaining the condition of the battery than by the colour of the plates. When first started, the negatives are yellowish grey, and the positives dark brown, spotted with a whitish substance. If the first charge is carried on long enough this whitish material disappears, being the objectionable sulphate deposit, and from this time the colour becomes the test.

.The positives should be a dark red, chocolate, or plum colour, but when fully charged they become the colour of wet slate. After a small discharge they regain their former appearance. If too much discharged the white deposit reappears in patches. The negatives soon assume a pale slate colour, which darkens slightly as the charging advances, but they are always much lighter in colour than the positives. The upper edges of the positive plates generally appear grey, but this is of no consequence if limited to these parts.

A few words on unpasted plates before going to the next chapter.

These, as before mentioned, require occasional reversing, which is a most delicate undertaking. The charging current at these times requires to be very small at the start, and increased as the operation advances, unless these precautions are taken the plates scale, and the cells become short-circuited. So far, these cells have not proved much of a success, on account of these troublesome reversals being necessary, which have to be done several times after leaving the factory. Notwithstanding the losses which must exist by the use of an accumulator, still it is an economy in private installations. There is no need to run the engine and dynamo at hours when only a few lamps are required, and these hours are many. Besides, the light is never cut off for a moment day or night, and a feeling of safety exists from the knowledge that a breakdown need not be feared. Another advantage also exists, that during the cleaning of machinery, or slight repairs there is a sufficient reserve to ensure light over the span when darkness would otherwise ensue, at great inconvenience.

It is well to remember the following: the hours from six a.m. till sunrise, and sunset till eleven p.m. for the whole year are 2,075, or, say, in round numbers, 2,000; these figures are a guide to the number of hours during which one or more lamps are required.

CHAPTER IV.

DISCHARGING.

FOR pasted plates the rate of discharge should not exceed four ampères per positive plate in a cell of the E.P.S. L type. This is at the rate of 6·1 ampères per square foot of positive plate. Returning to our old examples: For a 15 plate E.P.S. or E.P. cell, 28 ampères should be the maximum current for discharge; in a 23 plate cell, 44 ampères; and a 31 plate cell 60 ampères. The discharge may therefore always be larger than the charging current, which is often an advantage. It is moreover, found that the larger the discharge the lower is the internal resistance of the cells at the time, so the accumulator to a certain extent becomes its own governor.

The current starts at one point in the circuit, to return to it, but on its road it gradually loses its pressure, *i.e.* E.M.F., therefore the pressure of the current differs at all points, and its fall at any part of the circuit is in proportion to the work it is doing. Now, if the E.M.F. of one cell is two volts, of two cells four volts, etc., it is evident the total E.M.F. is

only obtained between the ends of the battery; and in dealing with one or two cells for testing, low E.M.F., measuring instruments, or, as generally called, voltmeters, suffice, but such an instrument would be destroyed if used to measure a high E.M.F., and one made to measure high E.M.F. would be unsuitable for low E.M.F., excepting in combination instruments, which are really equivalent to two separate voltmeters. It is with a low E.M.F. voltmeter that the state of each cell is examined. If in any cell the pressure is below 1·9 volts, then it requires charging, and if the other cells are charged, then this one must be cut out of the circuit during discharge, and replaced when charging. The cell is not moved, only the connections are altered for the time being. There must always remain about 25 per cent. of the total charge the cell is capable of taking, otherwise troubles arise; so the moment the E.M.F. of the battery falls below an average of two volts per cell, charging must be resorted to. When the plates are nearly discharged, that is, far below the point permitted, nearly all the paste on the positives is in the form of $PbSO_4$, and this soon decomposes into the higher sulphates which ruin the plates, and, apart from other consequences, cause them to buckle when charging is proceeding. It is therefore essential to keep a residual charge sufficient to give an E.M.F. of two volts per cell. In fact, after being fully charged the cells may be steadily emptied to the permitted limit, giving practically two volts per cell all the time; then comes a rapid fall, soon reaching zero

point. Too rapid a discharge buckles the plates, and very sudden discharges drives the paste out of them, although the current may be well within the maximum; therefore, when motors are started, it should be done through a variable resistance, apart from the requirements of the motors themselves. Similarly, very large batches of lamps should not be simultaneously turned on. Quantities of gas are driven from the plates at the moment of sudden large discharges, which does the injury. A large sudden discharge may be regarded roughly as one of 30 per cent. of the maximum. If a cell in the battery should be dead, *i.e.* give no E.M.F., from overwork, then, if not at once attended to, and cut out of the circuit, during discharge, the outgoing current will pass through it, and start charging the cell in the reverse direction, converting the positive plates into negatives, and *vice versâ*. This will naturally destroy the cell, because when charging is started the opposite action takes place, and in the end the plates sulphate, buckle, and lose their paste. Such a cell will also produce a counter E.M.F. of two volts, so the total loss of pressure will be that of the cell itself plus its counter E.M.F., in other words a cell giving no E.M.F., lowers the E.M.F. on the circuit, equivalent to the removal of two good cells. But if it is dead by reason of plates touching, or short-circuited from any cause, the loss of E.M.F. will only be that of the cell itself, as it sets up no counter E.M.F. in this case. To give a general idea as to what is the storage capacity of cells in practice, take a 15 plate E.P.S. or E.P.

cell, this is given as 300 ampère hours available, and since the maximum discharge is 28 ampères, say 30, it is evident that this can last for ten hours, and still leave the required residual charge, if the discharge is at a lower rate, then the time occupied to empty the cells will be proportionately longer.

For cells of the unpasted type no remarks are necessary regarding their discharge. The only limit is when the E.M.F. falls considerably on increasing the current.

We must now turn to Failures: the Causes and Remedies.

CHAPTER V.

FAILURES: THEIR CAUSES AND REMEDIES.

THIS part is probably the most interesting to the majority of those who possess installations, because the batteries are generally put up by the makers, and the theory has not an interest to everyone; but when difficulties arise in daily working energy is at once called for.

There are two troubles which beset most accumulators —buckling of plates and bad forms of sulphating, all difficulties may be traced to these, with few exceptions. It may be said with truth that buckling is almost unknown in well-managed installations. When cells are left to rest for a long period they should be thoroughly charged, and once a month afterwards a good charge should be given them. This will keep the plates from sulphating, arising from total discharge by leakage and local action, which always exists in a small degree. If by any chance the positive plates should sulphate, which is shown by the chocolate colour turning greyish all over the surface, or in patches, the action must at once be stopped or the battery will be spoilt. The colour of the edges of the plates give an indication of what is taking

place over their surface, so if the difference in colour between the positive and negative plates is not very marked, a careful examination should be made. The results of bad sulphating are scaling, falling out of paste, buckling, and short-circuiting. The causes may always be traced to the following: acid solution too weak, but more generally the cells have been habitually too much discharged, or left standing for a long period with little charge in them. Short-circuiting naturally will do this also, since the plates become discharged. A leakage in the circuit may discharge the battery unknown to the user. Bad insulation of the cells themselves will do the same thing. An easy test for insulation of the accumulator is to wet the back of the hand with weak acid and place it against the shelves. If the insulation is faulty a pricking sensation is felt, which is painful if 100 volts are used. If higher voltage is employed it is not safe to make this experiment. At 200 volts the shock is strong, but varies with every individual; for some people do not object to 210 volts, whilst others cannot stand sixty, especially those who suffer from damp hands.

All currents may be regarded as dangerous to the person after 250 volts, but the harmless pressures of 60 to 100 volts may prove highly dangerous under peculiar conditions; for instance, a man may be on a pair of steps, placing a new lamp in a fitting, and then unexpectedly get a slight shock due to leakage or otherwise, and the start it gives him, cause a fall from the steps; it is therefore always advisable to cut both leads when anyone is attending to fittings, etc. To return to the cure for sul-

phating, a continual charging below maximum rate, half to start with, for a prolonged period, will gradually reduce the unhealthy sulphate to the healthy form (*i.e.*, Pb_2SO_5 to $PbSO_4$), and finally charge the plates by conversion of the $PbSO_4$ to PbO_2. The task is tedious, but must not be hurried or the positives are certain to buckle. Most of the white sulphate will fall off in scale, and should any stick between the plates it must be pushed down with a piece of stick or flat strip of ebonite which is best. This white sulphate is a very bad conductor, so the exposed surface of the plates in the battery is much reduced by its presence. The maximum current is therefore too large, the current may be increased as the white substance falls off or disappears. If the sulphating has become very bad, it often separates with the blocks of paste attached to them. This is very vexatious, for the capacity of the battery becomes much reduced by this loss of active material, and great trouble is experienced in getting these pieces from between the plates, which short-circuit the cell if not removed. It is a good plan to clear a little of the deposit off each positive with a stick, and so offer some healthy surface to the current, lowering the resistance of the battery, and facilitating the reducing process.

Where the fault is great, the best plan is to clean the battery properly. After bad sulphating the capacity of the cells must always be less, in consequence of the loss of some of the active material. The cleaning of a battery consists in removing the sections from the cells, taking them apart and scraping the white deposit off the

positives. There is no need to take the plates off the lead strips, for by bending them apart there is plenty of room for manipulation. The wire brush material, sold under the name of carding, does the work well. A piece of this is cut to six by four inches, and nailed to a block of wood an inch thick, this brush is now applied to the positives till they appear their proper colour, and finally washed with the electrolyte, not with water on any account, or sulphating will start immediately. This done, the cells are again made up, new solution being employed, they are ready for immediate charging, and for a time regularly over-charged and watched. The cells also should be cleaned at the same time from any deposit. The old acid answers well to wash the plates with, and to place the negatives in whilst waiting, for these become injured by exposure to the air. The acid may finally be used to destroy weeds on roads and paths, so that nothing need be wasted. There is considerable risk of accident from short-circuiting if a cell is moved with the liquid in it, therefore, unless skilled labour is employed, it is best to syphon it off with a three-eighth red indiarubber tube, filled with solution by dipping it bodily into a vessel of liquid and then keeping the thumbs over the ends to prevent escape, whilst it is applied to the cell. Under no circumstances suck the tube to "draw the syphon." This proceeding is very dangerous, from the nature of the acid and the liability to receive a shock. So long as the electrolyte touches the plates there is possibility of short-circuit, so this must be completely drawn off, and no accident can possibly arise.

If the positives are past recovery, it is cheapest to have a new set, which can be obtained from the makers at a very moderate cost in exchange for the old plates. The same process is gone through for buckled plates with the difference that these require to be straightened. To effect this, thin boards must be placed between every positive plate (or negative if these are at fault), so that all the plates are parallel and in the same position as when in the cell, or the connecting strip of lead will be bent. They are then laid on their side, upon the ground, and pressed till they are flat. A portable lever and a screw-press are also used for this purpose. Start charging as soon as the battery is reconstructed. When the negatives dry they become hot, probably due to the finely-divided lead in them oxidizing in air.

Negatives exposed to the atmosphere for a length of time show signs of blistering when used, and proves very annoying, for these frequently separate as scale and stick between the plates, thus partially short-circuiting them, and eventually causing the positives to sulphate.

Blistered negatives often exist which do not drop the scale, then no evil consequences follow, but the risk should not be incurred. With new cells the negatives often blister, from careless manufacture. If a cell becomes completely exhausted or by chance reversed, the negatives buckle, but as a general rule it is only the positive plates which are subject to this trouble. It is always advisable to charge well before cleaning or straightening plates, because the air does not then act so prejudicially upon them. If the positives sulphate the sur-

face becomes very hard, but when in good order the paste as well as the surface of the grid are soft, and the colour comes off readily on the finger, like pigment. As a last resource it has been found that the addition of common carbonate of soda (used for washing purposes) helps the current to remove the white sulphate, if added in solution to the faulty cells in moderate quantity. Such a proceeding should not be resorted to till all other cures have failed and new positives have been decided upon. When the latter get in such a bad state the negatives are generally in a similar condition. The soda sets up a reaction due to the presence of an impurity in the shape of caustic soda which helps to reduce the higher sulphates. After this treatment, should it prove successful, new solution should be placed in the cells. Much loose scale from positive or negative plates may be removed by taking the sections apart and agitating the sets of plates separately in a cell of liquid. Buckling may also be caused by too high a charging or discharging rate. It also often arises from pieces of loose paste sticking between the plates which causes an unequal resistance between the surfaces, so that expansion and contraction is not symmetrical, and when this occurs the plates are often of a good colour. In all cases the framework or other means employed to keep the sections together must be so made as to allow for the expansion of the positives. The allowance need be very small since the plates are put together in the expanded form, but slight after-variations should be taken into account. Sometimes plugs of paste drop out when everything appears right. The cause is

usually found to be that a large discharge has been taken suddenly, therefore this proceeding should be avoided.

If a film appears all over the inside of the cell partially obscuring the plates, it shows that the water mixed with the acid was impure. When it occurs much inconvenience arises from the inability to see the edges of the plates properly, but no actual harm is done, and it can be entirely avoided by allowing the solution to settle after mixing, and to bale it out without disturbing the sediment. A slight quantity of powder will always be found at the bottom of the pots, and consists chiefly of the white sulphate removed during the first few chargings. The plates must never touch the bottom of the cells. Therefore observe occasionally the condition of the bottom block or frame. A temporary cure for plates buckling, is to insert glass strips or wooden wedges to prevent adjoining plates from touching, but the cause must be removed the first opportunity. It sometimes occurs that the dynamo leads have been wrongly connected, in which event the plates throughout the battery become reversed, and the negatives become brown and the positives slate colour. Such a mistake ought to be carefully guarded against, but should it occur there is only one remedy; namely, discharge the battery completely through a resistance frame or the lamps, so that the maximum discharge is not exceeded. This resistance may be reduced as the E.M.F. becomes less. When the accumulator gives no E.M.F. or at any rate a very low one, the dynamo wires must be correctly joined up and charging started very slowly at first, and with a resistance in one

of the Dynamo leads to keep the current small, since there is little or no counter E.M.F. to overcome till the cells charge up in the right way. Running the dynamo slowly will answer the purpose, but a resistance is more convenient. It will take a long time to get the plates in good order again, and perhaps many troubles will ensue, each of which must be treated in the proper way but matters soon mend if the mistake is discovered early. A resistance frame, called for brevity a resistance, consists of a frame of wood with a number of coils of iron, german silver, or platinoid wire stretched across it, having in appearance a number of spiral springs placed close together. Arrangements exist for permitting the current to flow through one or more of these coils so that the opposition to the current may be varied at will. The wire is proportioned in its section to carry the desired current.

If a cell gives no E.M.F. from any cause except complete short-circuit, then the discharging current has the effect of charging such a cell the reverse way, and the plates become reversed. The proper course to pursue is always to disconnect such cells when discharging, by bridging it over with a wire and to reconnect when charging. In time the cell will become charged equally with the rest, and it can then be permanently replaced. It is unnecessary to cut both connections of a cell, one end is sufficient. For instance, disconnect the positive strip of the dead cell from the negative of the next, and clamp one end of a wire to the negative strip of the dead cell (equivalent to positive of the adjoining one) and the

negative strip of the next cell, from which it has just been disconnected. When the charging commences be careful to remove the wire before connecting up, otherwise the cell will be short-circuited through the wire, damaging the plates and perhaps causing an accident by fusion of the wire, if too small. To avoid these operations, a two-way switch, suitably connected, will put the cell in and out of the circuit at pleasure. All leads in the accumulator house should be so placed that if the insulation wears off by the action of the acid and fumes, no damage will arise through short-circuits. They may be carried on porcelaine insulators, and every wire kept apart in all cases.

Never add concentrated acid to the cells, the ~~girds~~ grids will soon become rotten if this is done. Never test if E.M.F. exists in a cell by "flashing," which means taking a short wire, placing one end firmly on the positive strip of a cell and rapidly touching the negative strip, giving in this way a flash, if the cell is right. It is the old method of testing, which soon spoils the cells if frequently done, and no scientific result is obtained. The proper way to test is with a voltmeter, as before described.

When the plates are sulphated the internal resistance of the cells is greater, and consequently the E.M.F. for daily use is much lower. Also their capacity is less. Charging continued till boiling occurs, without further observation often leads to error; for clearly the less the capacity of the plates the sooner will the phenomenon occur, and all is declared to be in good order; whereas a

great fault may really exist, for the plates may be in bad condition, much paste lost, or many cells dead. The boiling in the latter case arises from the charging current being too great, since much counter E.M.F. has been removed. Again it may happen that no amount of charging causes the cells to boil. This indicates that nearly all the paste has fallen from the plates. Even in this condition the cells act as regulators to steady the light, but have scarcely any capacity. If at any time the plates of a fully-charged cell are removed from the liquid, then when replaced the s.g. of the liquid put in should be the same as it was before removal. If acid of a lower s.g. is put back, no amount of charging will appreciably raise it, because the plates being chiefly composed of PbO_2 when charged, there is little or no $PbSO_4$ which can be converted to PbO_2. At all times when a cell is charged as much as it is possible, whether the plates are in good or bad order, a point is arrived at when the acidometer indicates no further change in the s.g.

Till recently the ~~girds~~ grids were made of lead, now an alloy of lead is employed which is much harder. Apart from many advantages arising from this, there is one which claims attention, that of the possibility to re-paste the plates if required. The first expense of a battery is so large, and the renewal of the whole of the plates in the cells so expensive, that it pays the owner to re-paste his plates when it becomes necessary. With proper attention and fair usage years may elapse before this is required, but the method of doing it is given for the benefit of those who may wish to act

upon the suggestion. The value of the process may be estimated, when it is stated that the author had a battery of fifty-four cells which lost most of the paste, and its capacity became very small. The whole battery was re-pasted by unskilled labour for an expenditure of about ten pounds, resulting in a battery as good as new. Sometimes only a cell here or there wants renovating instead of the whole set. Proceed as follows: take the sections to pieces and spread the plates a little. Start with the positives, and mix up a stiff paste of red lead and H_2SO_4, one part commercial acid to two parts water. The paste eventually assumes a dark reddish brown colour, and more acid must be added until all the appearance of red lead is gone. We then have a paste chiefly composed of $PbSO_4$. It is possible to buy $PbSO_4$, and it is well to do so, being purer than a mixture of red lead, which generally contains much carbonate. The spreading apart of the plates allows the hand to reach every part of each grid, and the paste is best laid on with a small wooden board, and the surplus scraped off with a piece of iron hooping. The plates are now bent back to their normal position and set aside to dry. The paste should then be perfectly hard and adhering, if not, the consistency of the paste was at fault. A few trials will determine this point. A twenty-four hours drying in a moderate temperature is sufficient, they are then finished. The negatives are treated in the same way, only the paste is made with litharge. The sections are now made up, placed in the cells, and all made ready for charging. Probably thirty hours or

more will be required to form the plates, after which every hour of charging is storage, and the chocolate or plum colour of the positives is soon attained. Sometimes the forming is far more rapid. Re-pasted cells must be cut out during discharge until they boil, and in no case discharge a re-pasted battery till all cells boil. It is possible to paste the positives with PbO_2, purchased under the name of puce-coloured lead, when ready-formed charged plates are made at the start. It is found by many persons that the PbO_2 paste fails and soon falls out, but this has not been the experience of the author. There is a physical difference between pasting with $PbSO_4$ and PbO_2. In the first case it is laid on in the expanded form, and in the latter in the contracted state. If the manipulator can succeed with PbO_2 there is a great saving, since the cell is ready for a small discharge at once. Re-pasting can only be accomplished with economy when the grids are not rotten. India-rubber, if of good quality, does not deteriorate in the acid, but if bad it falls to pieces in a short time, a few hours even, may break it up.

There is little to be said regarding unpasted batteries, for beyond clearing any bad scales which may cause short-circuits, and occasionally straightening buckled plates, there is nothing more to be done.

So much has been said in this chapter on failures that it might be supposed an accumulator was simply a source of annoyance. This is only the case if not watched, and any little fault at once remedied. As a

rule very little trouble is given, and none at all if competent persons occasionally view the installation. In order to bring all the facts before the reader concisely, the following summary is added.

CHAPTER VI.

SUMMARY.

ALWAYS charge the cells until they boil well. Never allow the battery to run down till its E.M.F. is below the average of 2 volts per cell. If this should occur when it is known that the charge is not low, an examination of every cell should be made. The acidometers in the cells give an approximate idea of the state of the charge, if intelligently observed. Examine the plates every few days, by observing their colour, &c. No current meter is of service to measure the charge remaining in the accumulator, since account is not taken of local action and leakage which takes place before reaching it. As soon as only 25 per cent. of the total charge remains, the E.M.F. rapidly falls on further discharge. Precautions must be taken to guard against too large a current flowing when charging is commenced, also provision must be made against lamps being injured when turned on the moment charging is completed. The instant any fault is noticed, let it be remedied at once; and a dead cell should be cut out immediately. Do not charge

longer than necessary, but see that all the cells boil well; if any are much behind, observe if there is any obvious cause for this. Examine the insulation occasionally. Observe that the liquid in the cells does not become warm during charging. Test all measuring instruments periodically, so as not to fall into errors which may prove destructive to the plates. Feel all connections and switches occasionally to see if they become warm. Do not take advice for a remedy from the last person who gives it, before assuring yourself from some competent person whether there is value in the suggestion. Amateurs often act in this way, and generally the result is that a heavy penalty has to be paid, unfortunately not by the person who caused the mischief. At all times possessors of an accumulator should not spare money in sending for competent persons to set any fault right, for a trifling matter grows very serious in a short time, and by this course much good money is saved and vexation avoided. Above all it must be remembered that no rules unmixed with brains are of the least service.

PART II.—INSTALLATION WORK.

CHAPTER I.

ENGINES, DYNAMOS, ELECTRICAL MOTORS, AND THEIR TREATMENT.

THE first consideration is the prime motor. These may be worked by steam, gas, hot air, water, petroleum, wind etc. For installations up to 25 or 30 lamps a hot-air engine may be used, but in such cases by far the larger number are worked by gas engines, on account of their simplicity and the small amount of attention required; besides, no boiler is necessary, no extra insurance to pay, and no risk of any kind to be encountered. The "Domestic or Davey Motor" is good in some instances, but where water power can be obtained all the year round for no payment, it is the cheapest of all. Our attention will be confined to gas and steam engines, because these are the most common motors employed. For large installations steam is a long way the best, because gas engines of large power never prove themselves so satisfactory or so reliable as the steam engine. In fact after a 9 h.-p. nom. gas engine, a steam engine is the best to use. Taking gas engines first into consideration, the 9 h.-p. Otto, by Crossley, gives about 18 h.-p. indicated;

but since many horse-power are absorbed in working the engine, the useful or brake horse-power should not be reckoned over fifteen. But gas engines give off very variable powers from time to time, depending upon the condition of the slide, exhaust valve, temperature of the cylinder, quality of the gas, gas pressure, and other causes; it is therefore safe to expect on an average from such an engine only 12 h.-p., or say one-and-a-half times the nom. h.-p., for actual daily work. The smallest Otto engine, apart from toys, is the half h.-p. nom., which gives a large ind. h.-p. for its size, and one h.-p. may be taken as its useful power. After the one h.-p. nom., which is also advantageous for its size, all others may be taken as giving a brake h.-p. of one-and-a-half times the nom. h.-p. of the engine. The manner of working a gas engine, whether an Otto, Atkinson, Stockport, Bischoff, or of any other type, will not be attempted, for complete instructions are sent out with the engines, which are clear and simple; but a few suggestions will be made to fit them for the special requirements demanded, when these engines are used for electric lighting purposes. The Otto engine is so largely in use that the following remarks will apply to them, but in general they apply equally to other types.

Gas engines are all liable to stoppage, but with certain precautions this defect may be reduced to a minimum. Extra large oil cups should be put on all bearings and moving parts. Every place where oil is generally dropped in from time to time, should have automatic grease or oil cups. In short, the engine on being started

ought to carry sufficient oil for a twenty-four hours' run, even though not more than eight hours is likely to be required. The circulating water tank, when employed, should be extra large. To avoid the danger of the slide sticking or "cutting up" the springs or other arrangement in use on the back cover should be as free as possible. The chance of the slide light blowing out is thereby increased (in engines worked this way), so an additional protected burner should be placed in such a manner as to re-light the slide light in case of such an accident. A long fine jet answers the best, because the actual source of the flame may be six inches away from the slide, and out of danger from any puff which may come from it. The tight side of the belt to the dynamo should be on the floor side, which avoids the risk of the belt rubbing on the floor when it wears slack, for this often happens where the belt comes near the ground. A gas engine can be made to run the reverse way for a very small cost at any time, in order to get over the difficulty, when no other method is available. There are many good ways of cutting off the gas supply, electrically and mechanically, after a definite run, pre-determined upon.

Mr. Cunynghame's home-made apparatus is one of the best. A common clock, with a weight in the place of a spring, is used.

This weight falls a certain distance per hour. A scale is placed behind it, marked in hours. When the weight reaches the bottom of the scale, or zero point, it comes in contact with a lever, and the clock weight continuing to

fall, resting upon the lever, causes it to move and discharge a weight which turns a tap, cutting the gas off from the engine, which stops in consequence. To set the apparatus, the discharging weight is set, and the clock weight pulled up till it reaches a number on the scale corresponding to the number of hours the engine

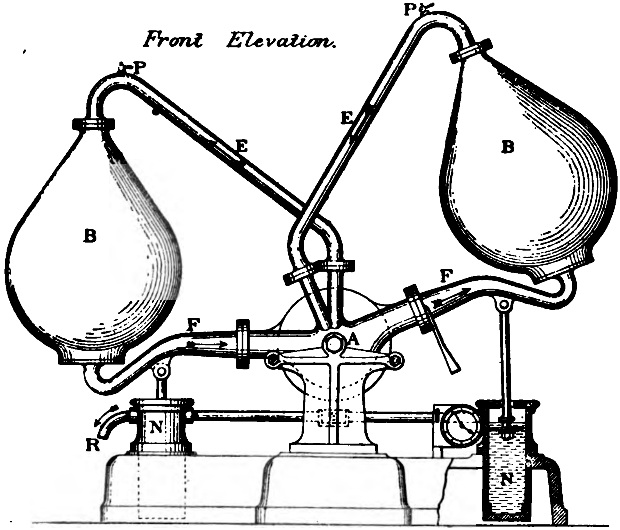


FIG. 6.

is to run. The latter is started, also the clock, and the operation is completed.

Steam engines, in the same way, should have very complete oiling arrangements, and money should not be spared in making all bearings adjustable. The boiler should have two methods of being fed with water. This

precaution often avoids a breakdown. The Fromentin Automatic Feeder (which is shown in figures 6, 7, and 8) is a safe and convenient way of keeping the water level in the boiler constant, without attention, and it relieves the driver as well as the owner from much anxiety. Recently a new paint has been brought out by Mr. Henry Crooks, C.E., which should be largely

Transverse Section.

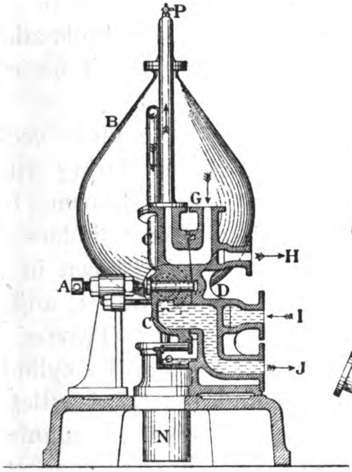


FIG. 7.

Elevations of Working Faces

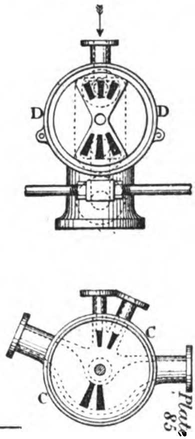


FIG. 8.

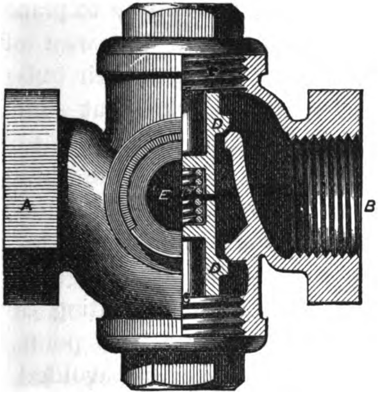
employed for all bearings, both of engines and dynamos. It is vermillion in colour, but as soon as its temperature is raised over 100° Fahr. the colour alters, and at about 150° Fahr., becomes dark brown. On lowering the temperature the original colour is restored, and these changes may be made any number of times without

altering the properties of the pigment, which is said to consist of a mercuric compound. For moving parts which cannot be touched to observe the temperature except at some risk, such an indicator is invaluable, and it may be used to show if electrical conductors are overheating, since 150° C, is the highest temperature to which conductors should be allowed to rise. It is only necessary to paint a small patch on every part liable to heat, so that a pound of paint would do the work of a dozen installations. There are a few more desirable additions which are of great value for engines used for electric lighting purposes.

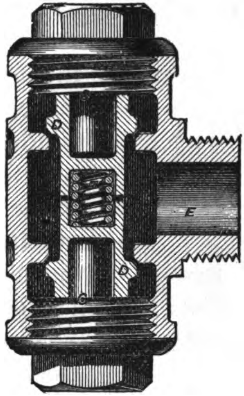
Every one is aware that unless the cylinder cocks are attended to on starting, at times during running, and on stopping, there is great risk of blowing off the cylinder ends by water collecting in the cylinders. There is a very pretty little apparatus made (shown in plates 9 and 10), consisting of two small valves, and three outlets, which gets over this labour. Two of these openings are connected with the ends of the cylinder, in place of the blow-off cocks, and the third outlet is led to a drain. The whole time the engine is running the valves work automatically, and the one connected to the end of the cylinder under no pressure, is opened at each stroke, allowing the condensed water to escape. When standing, both valves remain open.

Cylinder cocks may also be added if thought necessary. Over a three years' trial there has been no failure of the apparatus, nor has it ever required to be examined. As far as the author is aware, there is but

one firm who makes the apparatus, which is called the Aquajector, viz.: Messrs. Bailey & Co., and the price being almost nominal, its adoption ought to be universal. There is also a very neat form of fusible plug, recently introduced by Mr. Williams, by the use of which no tools are necessary to replace or test the plug at any time, and new fusible parts cost only 6d. The boiler insurance companies accept these plugs, so they may be regarded as reliable as they are convenient.



SIDE ELEVATION
HALF IN SECTION
FIG. 9.



CROSS SECTION
FIG. 10.

AQUAJECTOR.

DESCRIPTION.—A.B. Connection with either end of Cylinder. C. Screw Caps for cleaning, examining, or removing valves. D.D. The Valves which allow water to escape every stroke of the engine. E. Exhaust connection. F. Spring, which opens both valves whenever the engine stands.

Oil is a large item of cost in all installations, especially under the slovenly system of storing and using generally in vogue, for the waste is great. By employing

Richter's Economisers (see plate 11), a great saving is effected, and much oil may be used two and three times over by employing a filter combined with the economiser. These apparatus are inexpensive, and soon save their cost. Pans should be placed at all points where oil running through bearings can be caught; this waste oil is then placed in an economiser for future use, a separate one being employed for the new oil.

It is not intended, in speaking of these various conveniences, to advertise the articles, but simply to place most valuable resources in the way of those who may not be aware of their existence, and perhaps be working at some disadvantage for the want of them; for only five to ten pounds will add the whole of them to a small or large installation, with the exception of the Automatic Feeder, which also possesses the advantage of heating the feed water. The heating of the feed water is an important point. Much scaling of the boiler is avoided, straining of the boiler-plates through extremes of temperature is prevented, the steam pressure is more constant, and fuel is saved. A self-oiling sight-feed ought invariably be used for lubricating the cylinder, and the use of tallow and fats should be avoided. Grease cups for bearings are far more convenient than oil, and also cleaner. These need be replenished but once a month, if fairly large, so that the engine always stands ready oiled. There are many greases in the market,

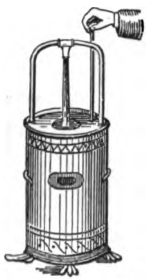


FIG. 11.—OIL ECONOMISER.

but after trying some ten samples over considerable periods, by various makers, English, American and foreign, only one has proved useful for every purpose, heavy and light bearings, fast and slow running shafts. This was supplied by Messrs. Elwell Parker, and it is remarkably cheap. Experience has shown that 5s. worth of this material goes as far as £5 worth of oil, and the friction is reduced quite as much by the grease as when oil was used. It is necessary, at starting, simply to adjust the grease supply to keep the shaft cool; this once done, no further regulation or attention is ever necessary beyond refilling the cups, and indicators on these show exactly the amount of grease left in them.

The contents of this book is supposed to apply only to private installations, so there is no necessity to go into the details which would be necessary in large works. However, a private installation is here supposed to go up to 3,000 lamps, this being considered a very wide margin, because the largest country-house rarely requires over 500.

Engines used for electric lighting should have automatic governors which "cut off" and "expand" in proportion to the load. It may be taken as a rule that the nom. h.-p. of the best manufacturers can be worked continuously to three times this number with economy, under maximum boiler pressure, but cheaper engines are not strong enough to stand a continual strain of more than twice their nom. h.-p. The maximum power at any time given off is clearly proportional to the steam pressure.

It is always safest in practice to purchase a steam engine required for a particular installation by the following method. Allow eight 16-candle lamps per brake h.-p., when the engine-house is within 100 yards of the house; if farther than this, seven to the h.-p., never less, because by making the leads larger this can always be obtained, excepting under peculiar circumstances, which would arise only in the event of great distances intervening between the generation of the current and the place where it is used, when it may prove cheaper to obtain less lamps per h.-p. than to have larger mains. Take for maximum brake h.-p. of the engine one-and-a-half times the nom. h.-p., there will then be no chance of falling short of power, and a good margin remains by raising the steam pressure slightly. The boiler should always have a larger nom. h.-p. than the engine to secure good steaming power, and longer intervals between the fueling. The higher the pressure of the steam, the more is expansion possible, and the greater the economy in coal, since the fuel required for converting the water into steam, which is very great and rendered latent, is not called for a second time to further raise the pressure, since all further heat supplied (with a trifling exception) assists towards useful work. Expansion beyond a certain point is best accomplished by the use of two or more cylinders, such engines being called compound. But these engines are not recommended for private installations, unless skilled labour exists, because the simpler the engine the less likelihood of its getting out of order. The same remark applies

to all high-speed engines, although in confined situations these are often indispensable. One hundred revolutions per minute of the fly-wheel is sufficient for all purposes in engines from ten to twenty nom. h.-p., and 150 per minute in smaller engines. After twenty nom. h.-p. the fly-wheels turn slower. All these engines come under the designation of slow speed. Much talk is made of saving fuel by the use of compound engines, etc., but to the private installer it is not of much consequence, as the saving is generally more than counterbalanced by the extra expense of locomotive tubular boilers, compound engines, etc., which require more attention than the Cornish multitubular boiler and simple engine. Higher boiler pressures also produce more anxiety. To give an idea of the actual saving effected in coal at 20s. a ton, in a year, for an installation of 100 lamps used 2,000 hours in a year, taking 6lbs. of coal for simple working per ind. h.-p. per hour, and 2lbs. for the most economical methods, would be £75 to £80 a year. Against this quite £30 to £40 would be required for faulty boiler tubes, drawing them for cleaning, keeping all fittings steam-tight against the high pressure of the steam, increased interest, etc. But this is an exaggerated case, for in no 100-light installation would it be possible in practice to light up to maximum 2,000 hours a year. The actual saving would probably not be more than £20 under the most economical method, which is a very small proportion of the total cost. The risk of breakdown is far less with lower pressures and slow running engines. It is strongly recommended to

insure the boilers and engine driver against explosion or collapse of flues; the expense is very small, and the company insuring makes periodical inspections, so all risk is taken off the owner. To give a rough idea of the cost, a boiler of twelve nom. h.-p., used with an engine of ten nom. h.-p., worked with greatest economy at 36 ind. h.-p., is insured in the Boiler Insurance Company, of Manchester, for £2,000, and the premium, including the engine driver, is about £5 a year. The insurance covers damage to buildings and machinery which might be caused by an explosion. It is therefore well worth while to take this precaution. If the engine-house is made totally inflamable there is no necessity to insure against fire. Much fuel is saved by banking up the fire at night, instead of drawing it, when the engine is worked daily, since the water is kept hot for the next day. This is a perfectly safe proceeding if an automatic feeder is employed. There should be two water gauges and two safety valves placed on the boiler to permit of perfect inspection and safety. Suitable boiler composition should be employed to prevent scaling, and in order to obtain the right kind, it is advisable to have an analysis made of the water. Indicating apparatus ought always to exist, by which means the working of the engine may be examined periodically, and undue mechanical and electrical waste checked. We may now turn to the counter-shafting and belting. Any good belting answers the purpose provided there is no raised joint. Chain belting has been much used, made of leather links only; those combined with iron or steel links are most

undesirable, but periodical examination should be made to observe the state of the links. Sampson's belting is expensive, but one of the best, and will last indefinitely. There is another kind of belt which comes from America (Cooper's), sold by Messrs. Churchill, of London, who are the agents. This leather has at least twice the strength of the ordinary material, and it grips exceedingly well, but for double belting it might be found to stretch when large powers are transmitted. This particular belting must be placed with the face side nearest the pulley, which is contrary to the ordinary practice. When counter-shafting is employed it is best to drive it by double belting, and carry single to the dynamos. Fly-wheel centre to shaft centre, about 15 feet, is the best distance. Belts should not be too tight, and the sag should be given at the upper, not the floor side; there is an advantage in this besides avoiding the risk of rubbing on the floor; a better grip round the pulley and better tension is obtained. Belt syrup should be used if slipping occurs when the tension is correctly adjusted, and the load not beyond the power of the engine. Sometimes a wave is produced in the sag of the belt which is reflected in the lamps by blinks. This can generally be avoided by making the machinery firmer, and sometimes, when this fails, by slightly raising or lowering the speed of the engine.

Counter-shafting should be solid, and all arrangements such that the belts may run horizontally, which permits them being left slack, utilising their weight for the tension, and saving the bearings from undue wear and

tear. It is best, when space admits, to place the engine and dynamos on opposite sides of the counter-shaft, the belt tensions then balance one another on the counter-shaft bearings, and much friction is prevented.

The action of oil in the bearings is peculiar. The shaft and brasses never come in contact, oil always intervening no matter what the load may be, so the friction really consists of shearing a thin surface of oil. It is thus seen why the "friction load," which means the power employed to run the machinery free, is about the same when a load is added, however great. The condition of course is, that the oil or grease is always being supplied to make good the loss. Hence, if the indicated horse-power to run free requires say four horse-power, and a load of one horse-power is added, the indicated horse-power will be 5, and so on. It is evident therefore, that the greater the load put upon an engine within its power the greater is the efficiency. In fact such an engine in practice would require almost the same coal and undergo the same wear and tear lighting one lamp as probably ten lamps, for so small a load would not produce much effect. Having now entered into many questions often not understood, or neglected by those who are unprofessional, it becomes necessary to look into the mechanical details of dynamos and electrical motors, leaving electrical questions alone for the present. There are endless patterns of dynamos in the market, but all those of the best makers give approximately the same efficiency, and possess the same qualities generally. The slow-running dynamo, say 500 to 700 revolutions,

should be chosen, there is less vibration and wear and tear than with machines speeded up from 1,000 to 1,500, but they are more expensive. It is imperative to have solid foundations, self-oiling arrangements for the bearings, and nothing answers better than grease for this purpose. The machines must be kept perfectly clean and not tampered with. For the mechanician all that requires attention are the commutator and brushes. Both must be kept scrupulously clean, and sparking in any form must be guarded against. All modern machines have the brush holders adjustable, so that full directions will be given to produce the best results. The commutator soon becomes worn by sparking or too heavy a pressure of the brushes. When much wear takes place the truth of the commutator becomes destroyed; instead of wearing down equally it gets eccentric, and all manner of shapes. Re-turning in the lathe is the only cure when this stage is reached, but this irregular wear can be almost entirely avoided, so that the armature, *i.e.*, the revolving portion, need not be removed for turning more than once in three or four years. If any plates in the commutator are softer than others, or contain flaws filled with solder, then nothing will prevent the unequal wear, except replacing these bad plates by good ones. Rolled copper is the best for commutator plates; it wears evenly, keeps bright, and no flaws can exist.

It must be remembered that if the commutator is not kept in good order the loss of efficiency may be enormous, and eventually it will be impossible to use the dynamo;

besides, the least unequal wear causes the brushes to jump and the light to flicker, and the faulty places become worse daily. When faults are confined to one or two plates they are termed "flats." Six things must be attended to for good running of these parts:—

1. The brushes must have a proper inclination.

2. The pressure must be adjusted properly.

3. The brushes must touch at the extremities of a diameter.

4. The lead given correctly for the current.

5. Occasional application of oil or grease to the commutator.

6. Scrupulous cleanliness in regard to the brushes and commutator.

1. The brushes in most cases may be more inclined as they are pushed further through the holders. The inclination is right when the commutator runs smoothly under them without noise, and they should offer a good surface to conduct the current. When new brushes are inserted they must have their ends ground or filed to the curve of the commutator. This is best done by clamping a brush in a vice between two pieces of wood so as to avoid spreading the plates or wires during filing. Unless a good surface of contact exists between the commutator and the brushes it is often difficult to obtain a current from the machine. When the commutator wears out of truth, the inclination must be increased.

2. The pressure need not be great, only so much as to insure perfect contact during running, more than this is unnecessary till the commutator wears out of truth.

Great heating of the commutator and armature is often due to the friction of the brushes when too much pressure is put on.

3. The commutator has usually two marks upon it indicating the opposite ends of a diameter, and the brushes must be shifted in their holders until their ends come to these points, when they will be diametrically opposed to one another. When such marks do not exist, the plates must be counted, and two opposite points may thus be found, and should be marked with a centre punch for future reference.

4. The lead next claims attention. The neutral points on the commutator are the two lines which can be drawn along the plates at the extremities of a diameter which coincides with the vertical or horizontal, according to the pattern on which the dynamo is built. These theoretically are the places where the brushes should rest, but in point of fact the neutral lines become displaced when a current is taken from the machine, and the displacement increases as the current is larger. The reasons for this displacement are not within the province of this book, so the consequences will only be considered. If the brushes are not placed upon these neutral lines sparking ensues, excepting in specially constructed dynamos, so all that is necessary to do for setting the brushes is to rotate them bodily on the frame to which they are attached for this purpose, until a point is reached when all sparking ceases, or is reduced to a minimum, and then clamp the frame. In good dynamos when the brushes are properly set and everything clean,

a point of no sparking can always be found. The angle between the theoretical neutral line and the actual one is called the "lead," which may be positive or negative. In the case of a dynamo the lead is positive, with a motor it is negative. When the brushes are advanced from the theoretical neutral lines in the direction of the rotation of the armature, the lead is positive, and varies in accordance with the current flowing into the brushes; when moved in the contrary direction a negative lead is given. In the older dynamos the lead was very considerable, but in modern machines one-eighth to quarter inch is generally all that is necessary for every current the machine has been made to give, and it is essential to advance or retire the brushes to suit the current, otherwise sparking starts when the current is much varied. Consequently it is always best to arrange matters so that whilst the machinery is running, a fairly constant current shall be used.

5. The commutator from time to time should have a little oil or grease applied to its surface. Grease is the best, and if made from petroleum, one application will last a day's work, provided the pressure of the brushes is light. The finger or a piece of rag is the best way to apply it; not with waste, as particles of cotton may get drawn under the brushes. A piece of grease the size of a pea should be the most applied at any time. Inferior dynamos require frequent lubrication. Some persons use blacklead, but this is undesirable because of its conducting properties, which must lower the efficiency of the machine. With alternating current machines this

substance may be employed, because the commutators do not consist of a series of insulated plates.

6. Cleanliness is essential, or sparking is certain to result: the least speck of grit is apt to start a "flat."

Copper dust cannot possibly be formed if all the precautions mentioned have been taken, but if any should collect about the machine it must be carefully removed. Undue pressure of the brushes produces copper dust in great quantities by tearing away the commutator, and this damages the machine; so when cleaning, these points should be observed, and all alterations should be done when the dynamo is standing, with the brushes raised. Adjusting the lead must be done when running.

It has been assumed that the machines are not of the alternate current type, because these are unsuitable for charging accumulators, and it is rare that these machines are in use for private work. If the attendant has any doubt as to whether the dynamo is acting, it is only necessary to bring a piece of iron near the field magnets, and observe if they are strongly magnetic; when doing this, care must be taken not to allow the iron to be drawn out of the hand, so as to damage the machine.

The brushes should on no account be lifted when the dynamo is running. The insulation may be much injured by this action, and a bad place is made on the commutator. In large machines such an act may result in a violent or even dangerous shock being given to the person doing it. The commutator at times

requires cleaning with fine emery paper whilst running slowly, and if in very bad condition a worn-out fine file may be employed when turning in the lathe cannot be resorted to, and in these cases remove the brushes so that they do not become charged with emery or dust. Of course, filing does not true the commutator, but mends matters for the time.

The temperature of the coils on the dynamo should never rise so high but that the hand may be placed upon them without inconvenience. It is well occasionally to feel the temperature of those parts which can be touched, provided the machine does not give a dangerous E. M. F. (*i.e.*, over 250 volts), and the armature can be examined for temperature when stopped. Many suppose that a dynamo sold to light fifty lamps cannot be used for more; this is not so, for ten times this number might be added in some cases, but the wire on the armature would become so hot that destruction of the insulation would take place, or fusion of the wire. The meaning of a fifty-lamp machine is simply that the wire on the armature is only large enough to carry a current for fifty 16 c.-p. lamps; so attention is necessary to observe that this limit is not exceeded by any accident or stupidity, such as putting fifty lamps on the circuit requiring a larger current than fifty 16 c.-p. lamps.

Electrical motors require exactly the same attention as the dynamo, the construction of the machines being identical (see figure 12), with the difference that the lead given must be negative. The speed of a motor is almost invariably higher than that of the machine

it has to work, so a counter-shaft must be employed in most cases, and this is better than wormwheel gearing, because many machines may be worked off one counter-shaft, if desired. It is best, in a workshop, to have a small motor to every machine, so that each workman may have his own motor under control. Notwithstanding that the loss from the engine to the lathe or other machine is probably 50 per cent., still electric motors are an economy. Heavy main shafting running all day is avoided. Ordinary main shafting, with the belts, probably absorb 30 per cent. of the power transmitted, especially when the alignment is faulty, and this is almost invariably the case.

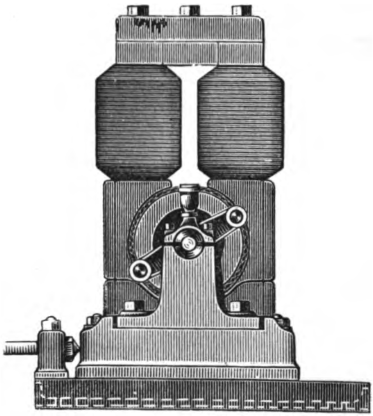


FIG. 12.–ELECTRIC MOTOR OR DYNAMO Elwell-Parker Pattern.

Again, although some machines are kept continually running, the majority will be found to be standing a good part of the day, not all at one stretch, but by summing up the stoppages. At such times a motor is stopped, and no waste proceeds, for the generating dynamo absorbs power from the engine proportional to the work demanded from it. Lathes, drills, etc., may be moved as found convenient, without considering the

position of the main shaft, which is a great advantage in itself.

In a private installation part of the power may be used for the estate shops, churning, etc., and even in the production of cold air in summer; in short, there is no limit to which the application of an electric motor may not be put for household purposes, without noise, dirt, smoke, or disagreeableness of any kind. Clutches are generally used with dynamos and motors in preference to shifting belts.

CHAPTER II.

SWITCH BOARDS, SWITCHES, INSTRUMENTS, LAMPS, AND WIRING.

SWITCH boards are not compulsory, but without them confusion is likely to occur, and frequent accidents, producing breakdowns. The apparatus is simply a board or piece of slate, with all the requisite switches and instruments placed thereon, for the convenience of having all together; so that at a glance the various positions of the switch settings, currents flowing, etc., may be seen.

In practice such boards are essential where smooth working is sought for. A diagram of a switch board is given here (in plate 13), but naturally they must vary very much in appearance, according to the requirements of the installation.

The chief essentials to be observed in the manufacture of this apparatus are the following:—The board to be of slate, by preference, and no connections behind. All conductors out of sight to be extra large, and of low resistance; all connections to be made on the front of the board, by means of terminals, cone pieces, or otherwise; all switches fitted on the front to

be capable of removal for cleaning or repairs. Such switches are best mounted on slate; the cost of slate and wood is much the same. All switches carrying large currents to be massive. If possible, it should be so arranged that no settings can produce accident. All switches, cut-outs, and instruments,

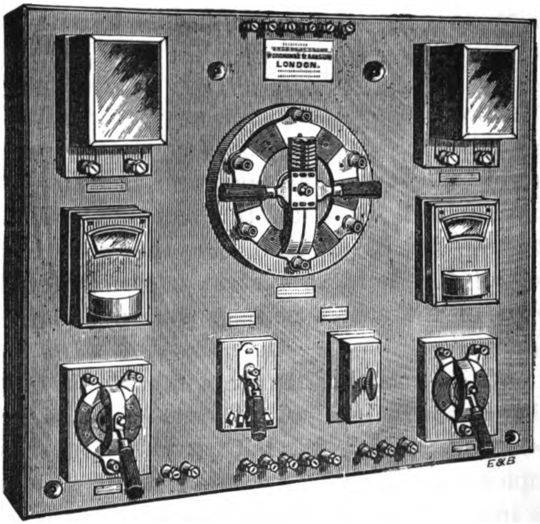


FIG. 13.—SWITCH BOARD.

should be fixed within easy reach. A diagram of the connections should hang alongside for reference. In a well-designed switch board, it should only be necessary to carry the dynamo leads, the house mains, and the accumulator wires to the board, all further connections existing upon the board itself. It is therefore

well to think over carefully what will be the requirements of the installation before starting this part of the work, because after alterations are troublesome, and destroy the appearance of the apparatus. Every terminal or other part liable to be short-circuited should be protected by covers of wood or glass. It is, therefore, best to place all switches, cut-outs, and ammeters

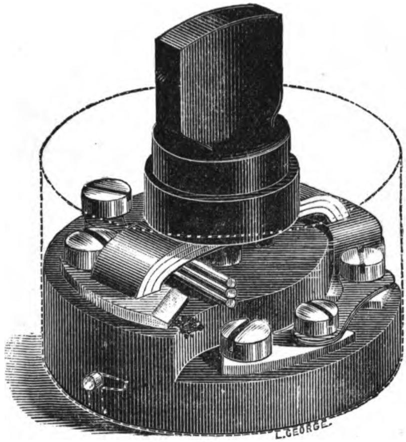


FIG. 14.—WOODHOUSE AND RAWSON'S LAMP SWITCH.

in the same lead, positive or negative, and to colour all positive parts on the board red, for distinction.

The next point is which kind of switches shall be used. There are cheap and expensive ones, some made for large currents and others for small. The latter generally come under the name of lamp switches, and carry one to ten ampères, according to their size.

There are probably no better switches in the market than those made by Messrs. Woodhouse and Rawson for the largest and smallest currents (see figures 14, 15, and 16). They have every requirement which such an apparatus should possess — perfect contact, smooth working, incombustible, parts easily removed for cleaning or repair, thoroughly well made, and cheap withal. Sketches are given of several of this type, single and multiple steps, also a compound switch, later to be described. These switches, excepting those for

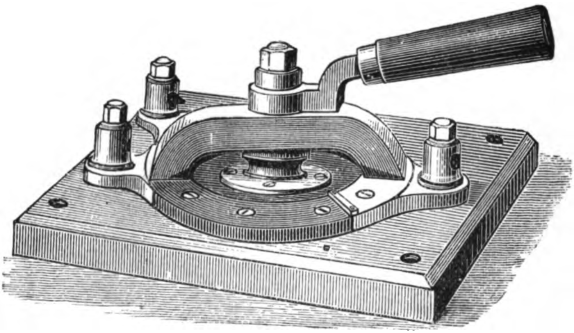


FIG. 15.—WOODHOUSE AND RAWSON'S LARGE CURRENT SWITCH.

lamps, are not intended to break the current, which act creates a spark and roughens the contacts; but special forms exist for effecting this without injury to the bright surfaces. When a current is put through an ammeter no spark is created, or at any rate it is so small as to be inappreciable. Very good cheaper forms of switches are those of Hedges (Globe Electrical Co.), the E.P.S. make, Compton's, etc. There is probably only one good

switch made for breaking large currents—this is the Siemens. Its principle is that the last break is taken off carbon points, so no metal is burnt; and when the carbon rods are consumed, which may not be the case for years, new rods worth a halfpenny will renew them in a moment. The action is thus: the metal switch is as usual, but, after the finger has broken the contact, the current still passes through two short rods of carbon, their ends being kept in contact by a spring or cam; on moving the switch-handle still further these separate,

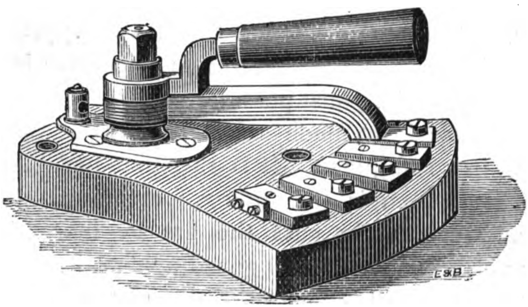


FIG. 16.—WOODHOUSE AND RAWSON'S STEP SWITCH.

with the usual spark if a current is flowing, and the circuit is broken. When closing, the carbon rods come first in contact, then the metallic parts. There is really no spark on making contact with low E.M.F.; it is on breaking that this is formed, and may be regarded as the momentum of the current which continues to flow during the cutting action. Many other switches have been devised to avoid sparking, such as the "many-break" switch, where the spark is divided into a number

of small sparks, also a step switch with a resistance between each step, reducing the current gradually, so that the total spark is divided over all the steps; yet none are so good as the "carbon last break" of Siemens, and it appears remarkable that these are not more in use.

The lamp switch requires another addition, some arrangement whereby on turning off, by no possibility can it be left half on, or in an arcing condition, *i.e.*, so that the spark created on cutting shall continue. The arc is broken if the finger moves through a sufficient distance. It is therefore found that a spring producing a snap action, or some equivalent, is necessary in these switches, to guard against possibility of fire. The bases and covers are best made of incombustible material, and fixed in a safe place. It is rare that harm is done, even if the switch is left arcing, for the metal burns away, and eventually cuts the arc by increasing its length; yet it is advisable to guard against it. When in doubt, the lamp will indicate the circumstance as it continues to glow, but very dull as if turned down. There is no simple way of turning down a lamp, although for this purpose switches containing carbon resistances exist, but they are not used, because the power absorbed by a lamp turned low is practically the same as when bright, so no economy is produced, and the lamps are so easy to relight that to turn off altogether is best. A smaller lamp is an economy, but the actual brightness of the filament is the same as in larger ones. So, when full and half-light are required, two lamps should be

used, and turn on one or the other at pleasure. Many kinds of lamp switches are made. Some, and by far the majority, turn on like a gas-tap; others pull out like a bell to turn on, and push in to extinguish the light; there are acorn-shaped switches, which are very convenient to attach to flexible cords by the bedside, etc. The Browett pull switch is fixed near the cornice, and by pulling a cord, the light is put on; also turned off by a similar action. In this case the wires need not be brought down the wall; also, by proper arrangement, the switch may be worked at a distance. Crompton's switches, Faraday's "Pointman," and many others are good. The author has brought out two kinds, one very similar to the Browett, but smoother in action, and more expensive to make, so it was not worth while to manufacture; and another one whereby every switch in the house is made capable of having a portable lamp attached to it, with an independent switch for this lamp, and now in the hands of Messrs. Woodhouse and Rawson. There are also magnetic long-distance switches, which at times are required. Wall plugs are most useful about a house for attaching a portable lamp or small motor at will. There is no better wall plug in existence at this time than that designed by Mr. Taylor Smith; the same may be said of his portable lamps, intended to be used with them.

It will be found convenient to put a safety fuse in every switch and wall plug. When a fuse melts there is then no difficulty in finding the point. Every lamp is also protected in this way, as well as each room,

against accidental short-circuits. The portable lamp has a reel of twin wire in its base, with the ends of wires going to the lamp-holder and a connector respectively. This connector fits the wall plug by pushing in the two pins it carries. The lamp, when so attached, may be carried to any part of the room, as the reel unwinds the wire, and this is rewound by means of a handle under the base. To give an idea of the meaning of a short-circuit, which is not clear to all, one example will suffice to explain its importance and danger. Take the case of a 100-volt current, supplying a 16-c.p. lamp which takes 0·6 ampère, and let the leads to the lamp have a resistance of 1 ohm (ohm is the standard of resistance). Now such a lamp has a filament with a resistance of 170 ohms approximately, so, when lighted, the passage of the current is opposed by 171 ohms, and this obstruction allows only 0·6 ampère to pass. It is clear that if the two wires leading to the lamp touch at any point so as to permit the current to pass from one wire to the other before reaching the lamp, it is cut out of the circuit, and 170 ohms are removed; therefore, 170 times more current would flow, burning up the wires, doing great mischief to the cells, and possibly to the dynamo, if certain precautions are not taken. These safeguards consist in cut-outs, which cut the circuit the moment the current exceeds a certain point. Every branch from the mains and secondary mains should have such a safety, and the mains also, in private houses. It is advisable to place all safety junctions within easy reach, and so constructed

that the circuit can easily be re-established without recourse to tools. Safeties are of two kinds, one is magnetic, and the other depends on temperature. The mains and branches are always laid to carry safely twice the current required, and with these conditions ten times the maximum current of the installation may be passed for a short period without risk, hence there is no necessity for these safety devices to cut the circuit for any special current so long as the setting is well within allowable margins. Fusible junctions are most commonly in use, and consist of tin-foil or wire, which melts on too much current passing, the section of the material being adjusted to the requirements. Mr. Alexander Siemens has shown that no danger to insulation occurs until a temperature of 150° C. is reached, also that no fusible junction should be employed which will melt till three times the current is passed which it has to guard. If the fuse goes at less current it gradually oxidises, and eventually the circuit is cut when not intended, and great inconvenience may be caused. We see that the 200 per cent. margin is really more than ample safety.

It would be of no service to the reader to enter into a description of the multitudinous devices existing for cutting the circuit due to rise of temperature, because the melting fuse is the best of all. One depending on the expansion and contraction of two different metals soldered together, is perhaps good, but not to be implicitly relied on. There is also an immense variety of magnetic cut-outs, which can be arranged to go off

for definite current, but of all of these Cunynghame's is the best, and a diagram of it is shown in plate 17. The current passes through mercury, but this is no objection. For ships' use a modification is made. When the current becomes too large the magnet draws up the armature with the arms, which dip in the mercury, and the circuit is cut, not to be re-made except by hand. These devices are extremely useful where cut-outs are likely to go often, such as those used with motors, and in the engine-house, since they can be reset at once, and a fuse takes longer and is more troublesome to replace. The best method is to duplicate cut-outs for currents over 10 ampères by using a fuse against all chances, and a magnetic cut-out set for a less current than the fuse. These act as checks one on the other, and permit of easy resetting at any time, since the magnetic cut-out goes first. All fuses should have incombustible bases and covers. In the house, there can be no two opinions as to the best places to put the

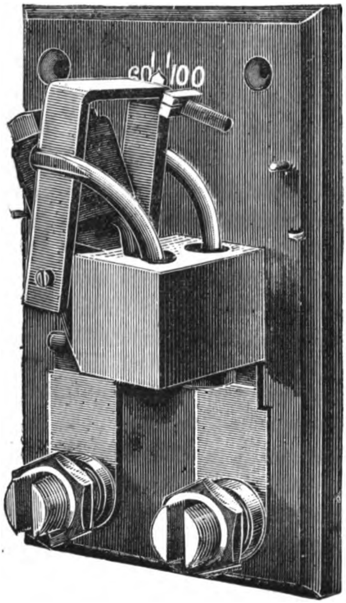


FIG. 17.—CUNYNGHAME'S MAGNETIC CUT-OUT.

lamp switches with their fuses, that is upon the shutting door-post or the wall close by.

In this way a room may be lighted before entering, first opening the door to obtain access to the switch; and by working upon a symmetrical plan the switch can be found in any room throughout the house; in the same way, in passages, some system should be followed. When "tap" switches are used, let the tap vertically placed be "on," and horizontally "off"; this saves doubt in the case of worn out lamps, broken circuits, etc. Having settled these points, there should be plugs for portable or fixed lamps, by all tables generally used for work, and by the bedsides, where switches may be painted with luminous paint. Many rules have been laid down for the number of lamps required to light a room, but they have no practical value on account of different decorations absorbing light more or less, and pictures require much illumination. A great deal depends on the positions of the lamps and the levels on which they are placed. The best and most reliable way is to take a number of good light-giving lamps, such as the kerosene duplex, and place them about the room high and low, till the desired result is obtained, and this test acts as a guide for the wiring, and the places where lamps shall be put. The most pleasant lighting is to place the lamps round the room about eighteen inches or two feet from the wall, and seven feet from the floor. This method is also most economical; and a few more to obtain light at special spots may be added, if the room is used to work or read in. Where a room is only

used for reception purposes the lamps may be placed ten feet from the floor with better effect. They are best used without fittings, simply suspended by flexible twin wire, and they may be obtained ground to avoid glare, or they may be toned down with silk shades. Ground lamps waste 15 or 20 per cent. of light, but it does not follow that this is a disadvantage or even waste in all cases. All incandescent lamps giving the same light absorb practically the same power, but it is different in the case of arc lamps, so the two must not be confused. For instance, a 100 volt 16 c.-p. lamp requires 0·6 ampères, or expressed in power by "Watts," $0{\cdot}6 \times 100 = 60$ Watts, thus if it is wanted to find what current is required by a 60 volt 16 c.-p. lamp $\frac{60 \text{ (Watts)}}{60 \text{ (volts)}} = 1$ ampères. To obtain 32 c.-p. 120 Watts are necessary, and so on. The vitrite holder remains still a prince amongst its competitors. Arc lamps scarcely come within the province of private house lighting, but a word or two may prove useful on this subject. Siemens, Crompton, Brockie-Pell, and many other lamps rank as first class. Woodhouse and Rawson make an excellent lamp for small currents, which is extremely steady. In all cases the pressure required for each lamp varies from 40 to 55 volts, and the light is no longer produced by an incandescent filament lasting some 2,000 hours, but by two carbon rods not in contact, the current jumping the interval, 1-16th inch in small lamps, to ¼ inch in large ones, its passage being indicated by a curved flame or "arc," but the light is produced by the incandescence of

the carbons at the point of separation. The positive carbon burns hollow or cup shape, transferring carbon to the negative rod which becomes pointed. In air the positive carbon burns twice as fast as the negative, and the positive carbon must face the direction in which the light is to be thrown. The arc flame is not visible electricity passing, but simply heated gases. Arc lamps require cleaning and trimming with new carbons daily, and therefore require much attention, and some protection against fire from falling pieces of incandescent carbon is necessary. A diagram of a 2,000 c.-p. arc is shown in plate 18, from a photograph taken by the author by means of two Nicholl's prisms at a distance of 16 inches from the arc.

The only instruments required in an installation are the voltmeter and ammeter. In most instances both are made in the same way, the difference being simply in the resistance of the wire upon the instruments. In the ammeter the current is required to give an indication of the quantity of current flowing without lowering the pressure, so they all have a very low resistance. The voltmeter is the reverse; it is here required to get an indication by absorbing the whole of the pressure of the current passing, and is placed not in the course of the leads, but between them, after the fashion of a lamp (except when these are in series). There are three kinds of instruments: one is the direct reading, the second must be set for

FIG. 18.
ELECTRIC ARC.

eac h reading, and the third may require setting or not, but the result must be ascertained from a table of reference. Then, again, all these may be divided into dead beat instruments, and the reverse.

The dead beat direct reading instruments are the most convenient, because the needle comes to rest at once, giving the correct reading on the scale, but they are liable to alter and require periodical recalibration. Some instruments must be observed away from currents and masses of iron. All kinds have their uses, and for accuracy many patterns should be employed to check errors. The best practical voltmeters and ammeters are he following :—

Siemens', which require setting, and a table of reference, although they can be made direct reading.

Ayrton and Perry's; one kind is dead beat and direct reading, but their spring form is not dead beat.

Crompton and Kapp's instruments are very reliable, but not dead beat.

Joel's, and Paterson and Cooper's are very convenient for engine house, when great accuracy is not required.

Cunynghame's is a portable form of Siemens', with certain modifications; this one requires setting, but is direct reading and dead beat.

Cardew's voltmeter is a most useful instrument, and depends on the expansion of a wire, and not upon the current itself, expect so far as its heating power.

Crooke's ammeter depends upon the colour of his special paint, and is only an approximate instrument.

The details of these instruments can be found in all

the best electrical text-books. All voltmeters should have the readings taken by allowing the needle first to return to zero, and in almost every case the current should be cut off at all times, except when an observation is required; but Cardew's voltmeter is the exception to these rulės. There are many meters for measuring electricity corresponding to the way in which gas is measured. They all depend upon one principle, namely, some means by which a train of wheels is made to revolve indicating needles upon dials, causing them to rotate faster or slower as more or less current is passing. Properties possessed by the electric current to put mercury in motion in a special form of apparatus forms Ferranti's meter, which is probably the simplest, best, and most reliable one at present existing. Some depend on magnetic properties, and Professor Forbe's with others on heat. Many years ago the author constructed a very accurate meter by means of a ray of light falling upon a mirror attached to a suitable ammeter, and was reflected upon a moving strip of sensitized paper. The darkened curve was afterwards integrated. Such an instrument would be too complcx for general use. Edison's meter is a thing of the past, depending upon the deposit of some metal. This instrument requires a shunt resistance, and therefore is wasteful for large currents.

We may now turn to the fittings. These can be to the taste of the owner; but the general mistake should be avoided of trying to make the electric light appear like pernicious gas. Gas must have a pipe, and this lends itself to ornamentation to hide its ugliness when long or crooked.

Again, gas jets at many points means complicating the piping in the walls, so groups of lights are resorted to. Electricity is devoid of all these drawbacks; there is no need therefore to group the lamps, which is a bad and wasteful mode of lighting, and there is no difficulty in putting lamps at any part of the room, although ready decorated and furnished; in short, the more conspicuous is the absence of fittings and groupings the greater the charm of the light and the more magic it appears.

Of portable fittings there have never been any to beat the designs of Mr. Taylor Smith for beauty, lightness, and practical use. A new fitting recently devised by the author, and taken up by Messrs. Faraday, to meet a want which he could not obtain anywhere, is simplicity itself, permitting a lamp to be fixed in a shade which can be placed at all angles, and pulled up and down at pleasure, simply by putting the shade as required, and there it remains. Each lamp so fitted takes the place of two or three for writing tables, work-benches, etc., and the eyes are shaded when desired. All suspensions and fittings should be easily removable for the time when a room has to be re-decorated. Although the incandescent part, which gives light in a lamp, is intensely hot, the volume of the heated material is so small that the temperature of the room is not appreciably affected, and of course no bad vapours are given off. Lamps may thus be placed close to tapestry, ceilings, or inflammable substances, without fear, for if the glass globe breaks the light is extinguished on the spot.

We finally come to the question of wiring. It is best

to obtain highly insulated wire braided on the outside, for small as well as large leads. The wire should have ninety-six to ninety-eight per cent. of copper in its constitution, and the section should be chosen proportional to the current which it has to carry, and always large enough to take safely twice or three times the intended maximum current. All wires and cables should be laid so that a small distance intervenes between them. The circuit should always be complete, so that the current is everywhere carried by insulated wires; hence measures must be taken not only against the possibility of short-circuit, but also against damp, which causes leakage, and injures first the insulation and then the wire. Cables can be obtained which may be laid in water, but the expense is great. The best way to lay all cables and wires is in wooden slips grooved with as many channels as there are wires to be run, the front is then covered with thin wood screwed on, for easy removal at any time. Leather saddles answer well to keep the wires in place. In damp parts, such as in cellars, the wood should receive a coating of pitch or Phœnix varnish, before the wires are fixed, and when these are laid a coating may be given to the wires themselves. The covering strip of wood is best fixed, not close, but a quarter of an inch away from the channelled wood, to permit a current of air to pass. Joints should be avoided in damp places, and in all cases they should be well made, perfectly insulated, and rendered waterproof with one of the many good compounds sold for this purpose.

All mains and branches should be laid on a system, and starting at centres, this is convenient for testing at any time, or for running a new branch. Wherever a branch starts, of smaller section than the main or branch whence it was derived, a safety junction should be inserted, and for extra safety, in case of leakage at any time, these fuses should be placed in both leads. But it is advisable that all fuses should be placed conveniently for examination or renewal. In rooms ready decorated, the wires need not be laid in casings and covered, except in places within reach, say, to six or eight feet from the floor. If the wires are fixed about one inch apart above the picture rods and under the cornice, they will then be completely out of sight. In houses wired before decoration, the casings may be laid level with the plaster or form a moulding on the skirting, dado, or cornice, but in every instance all wires should be easily accessible, and not laid in the walls or under floors. Where wires must cross one another or pass through a floor, etc., proper precautions must be taken to keep the wires apart, and from approaching anything of a combustible nature; for example, in traversing woodwork, an earthenware or metal pipe should be used to pass the wires through; and in all cases a plan of the wires, with positions of joints, etc., should be made. If any wires are outside the house not underground, lightning guards should be employed, otherwise there is no danger during thunderstorms.

Lamps can be placed in series, parallel, or in some combination of these two. In all methods,

except the parallel systems, high pressures are required, so for house lighting the parallel system is almost universal. The series methods take an important place in certain classes of lighting, for factories, public uses, etc. To give a general idea of the parallel system we will assume twenty lamps are to be used from a dynamo. Suppose from one dynamo terminal twenty wires start, and each wire has a similar lamp placed in its course before being returned to the other dynamo terminal. Let every branch have an equal resistance, then we have the current on leaving the dynamo dividing into twenty courses lighting twenty lamps, all equally bright, because the resistance of each circuit being equal, equal currents traverse them. This is the parallel system, but in practice it is not possible or convenient to start all lamp circuits from a point, so long large mains are laid, one from each terminal of the dynamo, and no connection exists between these mains except by branches connecting them, in which the lamps are placed. The resistance of the mains is so small compared with that of each branch with its lamp, that the resistance between point and point whence the branches start may be neglected, and we come back to the equivalent of the first arrangement. It is also evident that when the lamps at every point are required to be equally bright, large mains become a necessity, apart from the question of carrying the current safely.

CHAPTER III.

ACTION OF CELLS WITH DYNAMO.

IT is clear from what has gone before that when a dynamo is charging the cells, the E.M.F. on the lines is raised at least ten per cent., and this may cause injury to or break the lamps. When charging ceases before lighting hours, this is of no consequence, but in general there is no certainty of this being done, so measures have to be taken to keep the E.M.F. within the proper limits, at all times, on the house mains. The methods of doing this come under the next chapter, but this is the place to point out the circumstance.

Dynamos give different E.M.F.'s for different currents taken from them, when running at one speed; these variations may be drawn diagrammatically represented by curves called "Characteristics," and every dynamo has its own peculiar curve; a perfect machine would give the same E.M.F. for all currents when running at one speed, and the curve would become a straight line. Good dynamos have curves approaching this form for all currents within their capacity. The only form of dynamo which is best for charging an

accumulator is one shunt-wound. The series and compound wound are liable to have their polarities reversed should the E.M.F. at the terminals fall below that of the cells, when great damage may be caused before the cut-outs have had time to act. Messrs. Elwell Parker make a "Special Compound" wound dynamo for use with cells, but it is best to have the right thing at once instead of make-shifts. In a series wound machine the E.M.F. rises with an increased current; in a shunt-dynamo the reverse takes place, and the compound machine is wound partly series, partly shunt, so that the E.M.F. is practically constant at a particular speed for all currents. Let us confine ourselves to the shunt dynamo, this has a falling curve, *i.e.*, the E.M.F. falls as the current in the outside circuit is increased, due to two reasons, one is, the armature absorbs more power as the current is increased; and secondly, the lowering of the outside resistance, to obtain an increased current, is in shunt with a fixed high resistance, viz., the shunt winding on the field magnets, so that when the outside resistance is lowered to zero by short-circuiting the terminals, practically no E.M.F. exists, and no current passes. Again, as the outside resistance is increased, the E.M.F. rises to the work. It has been supposed by many that a shunt machine will always respond to the work in a definite and suitable manner. This is not the case in good dynamos, because by their construction (consult Professor Sylvanus Thompson's book on this subject) the curve is nearly straight for all currents within their capacity, and it is with such modern dynamos that we have to deal,

although those with falling curves are probably best in small instalations, where waste is not of great consequence. Dynamos give a different E.M.F. in proportion to the speed, but if a much higher E.M.F. is required than originally intended, then two things must be considered. The first is to ascertain whether the armature is strong enough to withstand the increased speed; and secondly, the shunt resistance must be increased by inserting an outside resistance, or the wire will become too hot. In dynamos intended to run at two speeds, it is usual to place the shunts parallel for slow rate, and series for the faster one; in this way the use of an outside resistance is avoided. The E.M.F. and speed are not exactly proportional, for as the E.M.F. rises, more current is sent round the field magnets, and the field becoming stronger, the E.M.F. has an increase due to this cause also, because the iron of the magnets is not near saturation point in modern dynamos, except in cases where they have been made for some special purpose. Yet within small limits, the speed and E.M.F. may be taken as varying together directly after the speed for which the machine was intended to run has been reached, generally called the critical speed. This term is used by different persons to imply different things; the definition should be, in common sense, that speed when the curve is nearest a straight line within the capabilities of the dynamo. The relations between the speed, field, and resistance on the armature, are the data which determine the E.M.F. and curve, and the diameter of the armature wire limits the current which can be obtained with safety. We have now before

us the general behaviour and qualities of the dynamo. Turning to the cells, their E.M.F. is practically constant, but rises somewhat as the charging proceeds, and mostly at the end of the charge.

Now, three things may occur when the dynamo and cells are combined.

1. The dynamo may have an E.M.F. higher than that of the cells, when they will charge.

2. The E.M.F. of the two may be equal, when no current passes.

3. The E.M.F. of the dynamo may be less than that of the accumulator—in which case the cells will discharge into the machine, and run it as a motor, and appliances should exist to prevent this.

Since the mains are branched from the ends of the accumulator—or, in other words, it would be more correct to say that the house and dynamo leads are one and the same, with the accumulator placed between them, in the same way as a lamp—it is necessary to examine what occurs when a current is flowing in these mains. Case 3 may be neglected, because it never occurs; should it do so, it must be regarded as neglect or accident. In case 1, it is evident that so long as the E.M.F. is higher than that of the cells, all current going to house mains must come from the dynamo; this, in fact, supplies the light and charges at the same time. In case 2, half the current is supplied from the cells, and half from the dynamo. There is, however, one more case in considering the house leads. It is possible to raise the E.M.F. of the dynamo slightly

above that of the cells, so as not to appreciably charge them, and yet supply the current to the house. This point the author terms "Balancing point," and an advantage is gained when this is the case, by obtaining a steady light. We have seen that to charge the cells the E.M.F. must be highest at the dynamo, therefore the circuit between this and the cells must not be completed till this is the case. By observing a voltmeter, and then moving a switch by hand, is one way,

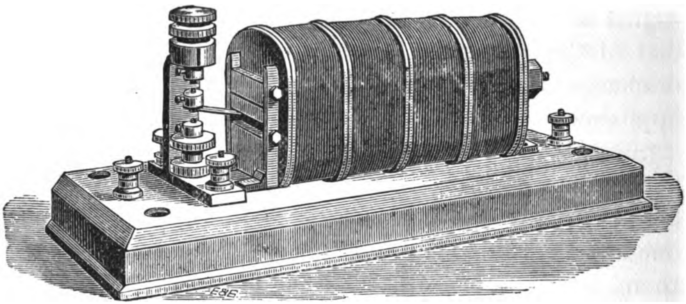


FIG. 19.—E.M.F. REGULATOR (REPULSION).

but by far the best is to have an automatic switch, whereby the current is put on when the correct E.M.F. is reached ; a diagram of such an instrument is shown, consisting of two parts ; one the E.M.F. regulator (shown in figure 19), which sends a current to a mercurial switch (figure 20) when the E.M.F. is sufficiently high, and it again sends another current when it falls below the proper point, in this way making and breaking, by means of this controlled switch, the dynamo and cells circuit. To avoid a shock to the

machinery the controlled switch is made two-way, the current from the dynamo going through a resistance capable of passing a current equal to the charging current, so that no difference is produced in the load at the moment of putting the current to the accumulator. As the E.M.F. of the cells rise and oppose

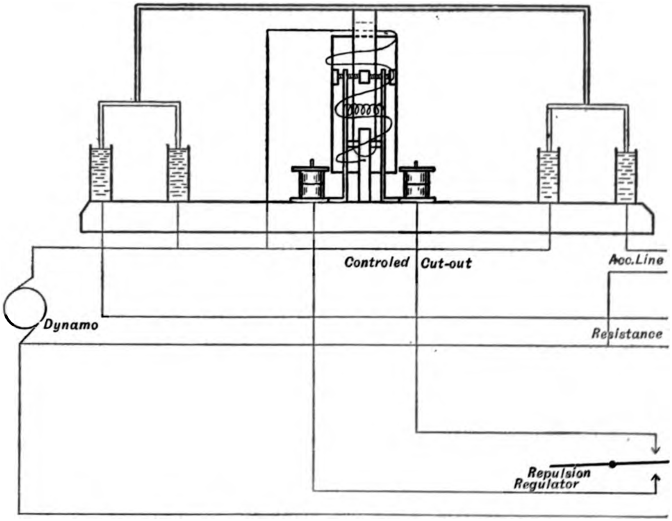


FIG. 20.—CONTROLLED CUT-OUT OR SWITCH, SHOWING CONNECTIONS.

the charging current, tending to lessen it, so also does the E.M.F. of the dynamo in a falling curve machine, but in the best dynamos this rise is inappreciable; so if the current is to remain constant certain devices in the form of governors must be introduced. A method of altering the E.M.F. of the dynamo is to

place resistances in and out of the shunt circuit by hand, and a fairly constant current can be obtained in this way.

The automatic means will be explained in the next chapter.

The resistances required to be inserted for this purpose are small compared with that of the shunt, so the characteristic of the machine remains unaltered, and sparking is not produced at the commutator if the brushes have been set for the load.

The cells tend to steady the light when the prime motor is slightly irregular in speed, either when no current is flowing through them, or when they are delivering a current to the lines at the same time as the dynamo. It is then that they keep a constant field for the armature to turn in, and the variations of E.M.F. at these times depend simply upon the irregularity of the speed, instead of variations of speed and field combined. At other times also, the cells steady the light, but not to the same extent, and their action then depends on the relation between the resistance of the cells to that of the lines, so that any increase in current due to a rise of E.M.F. is divided between the cells and the line in that proportion; and since the resistance of the cells is low compared with that of the lines, the bulk of the increased current passes that way, thus the current to the lines is kept nearly constant. It is therefore desirable to make the resistance of the cells as small as possible, apart from the other reasons already given.

It was shown by the author, some time back, that any counter E.M.F. arrangement of low resistance, placed between the lines, will steady the light when cells cannot be used, such as a motor kept steady by a fly-wheel, or doing constant work.

On more current being taken to the lines after balancing point is reached, the dynamo and cells begin to supply equal quantities, since the E.M.F. of the dynamo falls slightly for the increased current, and it does not recover itself again when the diminished current flows, because the strength of the field is now altered. It is evident that machines with very falling curves regulate automatically and very perfectly, but they are too wasteful in any but very small installations.

CHAPTER IV.

METHODS OF WORKING AND GOVERNING.

It now remains to explain the best way to effect the points mentioned in the last chapter: firstly, to keep the current charging the cells constant—a great convenience in practice, for, once set right, no further attention is ever necessary; secondly, to make everything automatic; and, lastly, to maintain a practically correct and constant E.M.F. in the house mains.

We have seen that the above cannot be obtained unless devices are put in to produce these results. We will deal with them in order.

1. To keep the charging current constant, no matter what the counter E.M.F. of the cells may be, and at times when the house leads are being supplied from the dynamo whilst charging, no matter what the characteristic of the machine may be, can only be effected in one way: by altering the E.M.F. at the terminals of the machine, in such a way as to produce the desired result. This can be done by speeding the dynamo for the highest E.M.F. ever likely to be called for, when giving maximum current, say, for instance,

25 per cent. more E.M.F. than the cells give. Then employ a variable outside resistance, which can be placed in the shunt by hand or automatically, to weaken the field, and thus lower the E.M.F. The resistance should be so adjusted that when the dynamo is giving ten per cent. of maximum current, the E.M.F. is about equal to that required on the house mains; in this way every possible E.M.F. that can be required may be obtained, since the resistance may be varied between these extreme limits.

It is also possible to insert variable resistances in one of the leads between the dynamo and cells; but it is a bad way, destroying the steadying power of the accumulator, and is also very wasteful.

The loss in using resistances for the shunt is *nil*, because, although there is a loss in this apparatus, it is more than compensated for by not requiring to reduce the pressure of the current after leaving the machine, so it is an economical method to obtain the desired result.

2. The last chapter mentioned the way to put the current to the cells automatically, but two more things are required to make everything self-acting; one is to make the charging current to the cells constant by means of a governor, in the way just explained; and the other to have a governor to keep correct and constant E.M.F. on the lines. The fact of keeping a constant charging current means a variable E.M.F., which is reflected on the lines if not governed, and the charging E.M.F. is also too high for the lamps; other-

wise, the E.M.F. would be too low from the cells when charging is stopped, unless some were shifted from parallel to series, which would eventually exhaust those cells, and such a method, therefore, is not desirable.

3. To maintain a constant E.M.F. on the house lines, the only way is to reduce the charging E.M.F. to the pressure required for the lamps, by some apparatus put in one of the house leads. This loss by reduction of the E.M.F. is absolutely inseparable from the system during the time of charging; and the necessary lowering of the pressure can be effected by placing a variable resistance, moved by hand or automatically, in the course of one of the leads, a method which is not good because the number of steps in the resistance must be very numerous and be varied not only with a change of E.M.F., but also for every current passing to the house, though the pressure may remain unchanged. By far the best and simplest way is that which the author devised some years ago, by putting counter E.M.F. in one lead in order to reduce the E.M.F. of the charging current for use on the lines. The chief advantage of this system is that one setting only is necessary for a particular reduction, and is independent of the amount of current flowing; thus, if the reduction in the E.M.F. has to be four volts, a counter E.M.F. of four volts accomplishes it for all currents; but had resistances been used, a different adjustment would have been required for every variation in the current. The counter E.M.F. consists of cells like those in the accumulator, but not charged, and water only is used

for the liquid. A current passing through these cells is reduced at the rate of two volts per cell, and a two-volt jump is not noticeable at the lamps, because the changes are made automatically at the proper moment. These variations could be effected by hand, but the way described is best.

The old method was to place one of the lines from the end cell of the accumulator to some other one, so as to include less cells between the lines, thus the excluded cells give a counter E.M.F. to the house current, and these cells have to carry the house current in addition to the charging current, so if those cells generally excluded are not larger than the others, or have shunts, they receive too large a current and become injured. In any case the plain cell counter E.M.F. method answers best, and is under better control. In large installations both methods may be used together with advantage; in simple installations this excluding of cells is done by hand, but an automatic two-way switch should be employed, identical to the one used to put the dynamo current to the cells, and worked by the same E.M.F. regulator, only in this case the regulator causes the switch to put one line from the last cell to some other one, at the same time as it actuates the charging switch, and the reverse actions take place on stopping the dynamo. It is clear that when much current is flowing in the house mains, the waste is less, and the dynamo E.M.F. approaches that required for the lamps; in other words, the charging current is reduced, and consequently greater steadiness is secured at the same time. It is best, there-

fore, to charge before lighting hours, and if the lamps are to be supplied from the dynamo, the governor should be set to make the charging current very small, so that the dynamo produces very little more current than is being used in the house. The best way to set a governor for this purpose is the following: Have an extra resistance placed in the shunt circuit and worked by hand, which is not generally employed; but when the above result is desired, gradually insert this hand resistance, the governor then responds, taking resistance out, since it struggles to maintain the original charging current; continue putting in resistance till the governor has worked all its own out; now every extra resistance put in by hand reduces the charging current. This method saves the operation of continually setting the governor for varying charging currents, which is possible but troublesome to do at a moment's notice, whereas the hand resistance method is very easy, and effected thus in practice: simply observe the ammeter showing the charging current, and move the switch handle which regulates the resistance, until the reading is that required. Nevertheless, it is sometimes not wasteful to charge at maximum and supply the house at the same time. This applies to large installations, where, by increasing the work, the machinery is run with greater economy. On these points discretion must naturally be employed.

There is another great advantage in the use of a counter E.M.F. governor. It is that when cells are disconnected for any purpose the dynamo can be

used direct to the house, as the arrangement governs the E.M.F. perfectly by reducing all above the normal to the correct pressure for the lamps. A few extra cells are desirable to keep the E.M.F. of the battery up to normal, should this ever be required, which is rarely necessary when a battery is properly attended

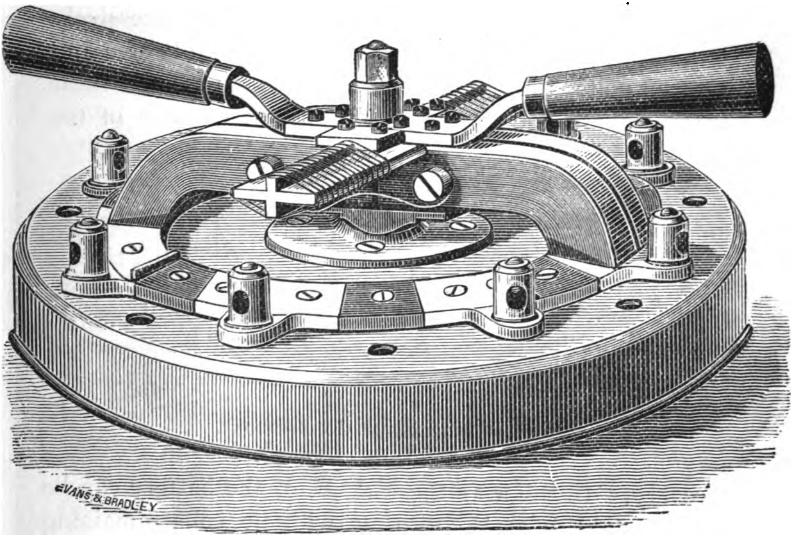


FIG. 21.—COMPOUND SWITCH.

to. The addition of extra cells requires an increased E.M.F. of the charging current, and therefore renders a governor on the house line the more necessary; but the author has devised a compound switch (shown in figures 21 and 22) whereby this increased pressure of the charging current is dispensed with, the extra cells are

no longer idle ones, and the advantage also exists of not injuring those cells excluded, when charging and lighting at the same time. The method consists in doubling the number of excluded cells and placing them two and two in parallel. For instance, say the last eight cells are so placed, giving eight volts; by moving the switch these cells can be shifted to series giving successively ten, twelve, fourteen and sixteen volts, or to twelve and sixteen volts, without intermediate pressures, and these increases are added to the E.M.F. of the rest of the

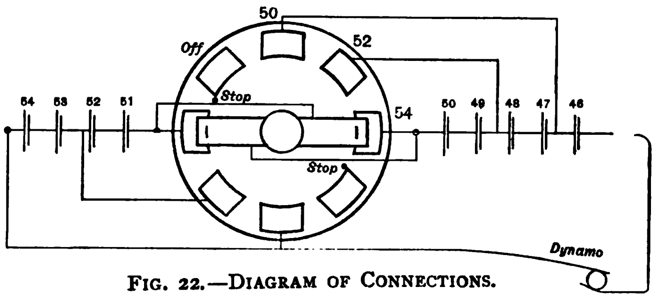


FIG. 22.—DIAGRAM OF CONNECTIONS.

battery. In this way the E.M.F. of the battery can be raised eight volts at any time, with no cells remaining idle; also when in parallel and excluded from between the lines, twice the maximum charging current may be passed without doing injury.

It is possible with the counter E.M.F. governor to use storage cells, so that when employed to reduce the pressure, storage takes place, then by a second automatic switch the wires on the cells can be changed end for end, when each step of the governor will add two volts

to the current instead of deducting it. This is too refined for practical use, but this possibility is shown in case of such a requirement. The cells used for reducing the E.M.F. must contain sufficient plate surface to pass the maximum current without giving off large volumes of gas. The size may be chosen by taking double the current which would have been employed if used for storage, and this will be the amount which can be passed conveniently.

The steps of this governor must have no breaks, or the lamps will be extinguished during the moves.

When storage cells are shifted one at a time on a switch without breaks, each cell is successively short-circuited, which causes a large spark on the switch contacts, rendering this apparatus unworkable and spoiling the cells; and when two or more are included in one shift the trouble increases. If the short-circuit is made through a small resistance, the E.M.F. of one cell being only two volts, the spark is very slight, and no harm is done to the cell; if a current is flowing to or from these cells, by putting a suitable resistance for the current most generally flowing, no spark is created. Messrs. Ayrton and Perry claim to have been the first to devise such a switch, but others claim precedence. Such a switch is made with two fingers close together with a very small resistance between them, which comes into use only when the fingers are moved, and standing on adjoining contacts. Both fingers must be on one contact piece when left; other forms exist to gain the same end.

We have therefore shown that to get perfect regulation and everything automatic, the following apparatus are required:

1. An automatic switch to put on the charging current when the E.M.F. is higher than that of the cells.

2. A governor to keep the charging current constant.

3. A counter E.M.F. governor to maintain a correct E.M.F. on the house lines.

For supplementary apparatus the following may be placed in the installation:

1. An automatic switch to exclude a given number of cells from between the lines when charging.

2. A compound switch to increase the E.M.F. of the battery, by shifting cells from parallel to series when required.

3. A hand switch in connection with the constant current governor, to reduce the charging current on special occasions without resetting the governor.

With these appliances, it is only needful to start and stop the engine, so that a man having no knowledge of electric lighting may be employed, and indeed the stopping may be done automatically with a steam engine, in the same way as was shown possible in the case of a gas engine in an earlier chapter, with slight modifications.

The general plan of an installation is shown in plate 23.

It may be pointed out that when a gas engine is employed, it becomes a very fair governor for the current from the nature of the engine, so that a constant current governor may be dispensed with, provided the engine is

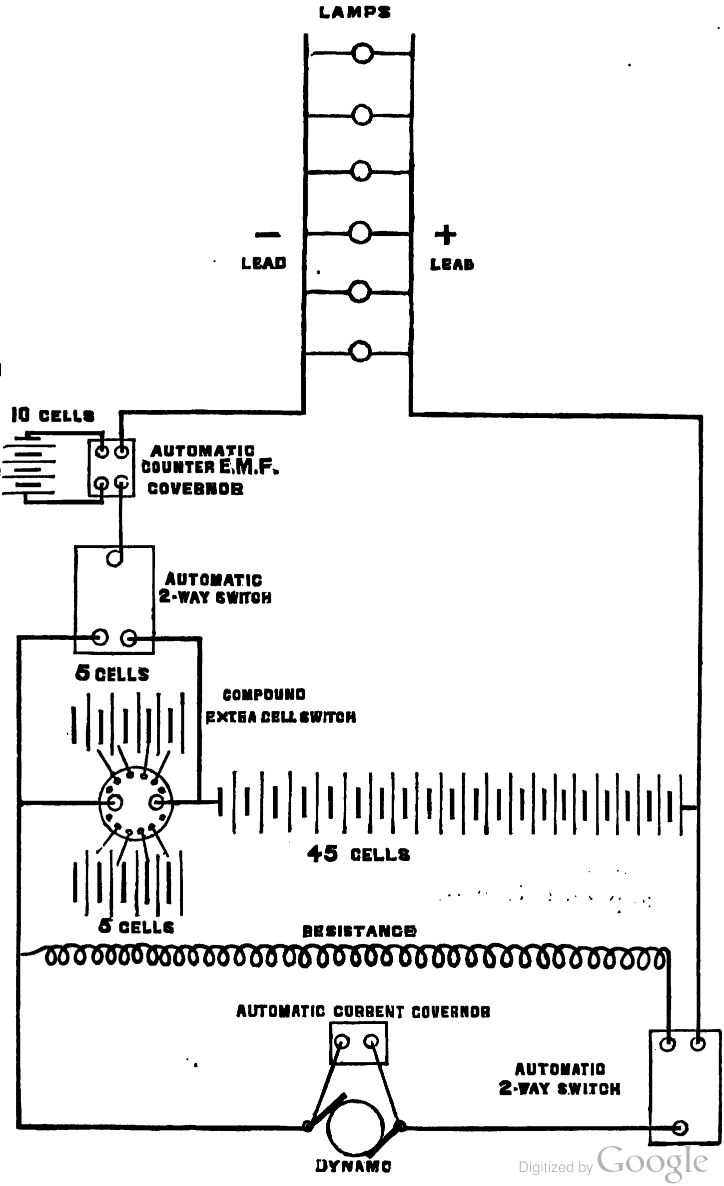


FIG. 23.—GENERAL VIEW OF CONNECTIONS.

not too large for the installation. These engines tend to run at their maximum power when the proper load can be given, and in the case of electric lighting this can usually be done, so that the Watts given by the dynamo are always fairly constant. The result of this is that during the charging hours the counter E.M.F. required to keep the pressure correct on the house lines is almost invariable, so a counter E.M.F. governor is also unnecessary, and all that is required is an automatic switch to exclude a definite number of cells. But in large gas engine installations the same governing arrangements are required as if steam engines were used; also in small installations where the power of the engine is beyond the requirements.

To draw the attendant's attention to the fact that the cells are charging at too high a rate, should such an event occur, an alarm may be employed, consisting of a very low resistance coil put in the course of the charging current. In this solenoid is placed an iron core, which is raised by its magnetic action as soon as the current exceeds a certain point, when a contact is made, causing a bell to ring. This bell may obtain its current from one of the battery cells, and it is made to ring for any current by adjusting the weight of the iron core. Such an apparatus is made by the E.P.S. Company. Messrs. Drake and Gorham have an apparatus worked by the temperature produced by the current, to effect the same end, but such appliances are more delicate.

An automatic arrangement can also be made to indicate when too high a discharge is taking place, and avoid

the inconvenience of being placed in the dark by a cut-out going. The device may be as follows:—When too large a current leaves the cells a special cut-out (magnetic) acts, putting a large resistance into the circuit, thereby restricting the current; when the current is reduced to the proper limit, the resistance is removed. In the house the following would take place:—When too many lamps are put on, the light of all would suddenly fall, but they would not be extinguished, so some of them must be turned off, and when the number permissible are on, the brilliancy is restored.

An electrical governor on the steam engine is of little use to obtain a very steady light, on account of the great momentum of its moving parts. All governors are best placed in connection with the dynamo and leads; and where an accumulator exists, a governor on the engine is valueless for constant E.M.F. as well as for constant current. It also costs more to put a governor on the engine than elsewhere, and by its position is more exposed to injury. There is a phenomenon somewhat resembling momentum in the case of magnetism, but it can be reduced to such an extent as to be of no consequence.

A governor placed to regulate the E.M.F. of the dynamo may work fast or slow; it may "Hunt," that is not reply at once to the call made upon it, but pass and repass the proper step on which the switch finger should remain, but this is of no consequence, for steadiness is soon established. The "hunting" is caused by the time required by the iron in the magnets to respond to the altered shunt current.

Before entering into the mechanical details of two first-class governors, the following special ways of working an installation will be explained. It may be truly said that few installations really work perfectly in all respects, through the want of proper governors or for some other reason. It sometimes happens in a small installation, where a gas engine is in use, that the dynamo and cells is both giving current to the lamps, and in this case the light is usually unsteady. The reason for this is that under such conditions the E.M.F. of the dynamo and cells is equal, and since every irregularity of speed, which is considerable with gas engines, produces a rise or fall of E.M.F. at the terminals of the dynamo, at one moment the cells are giving all the current to the lines, and perhaps even making a motor of the dynamo, and at the next the dynamo is giving all the current, and also possibly charging the cells at a very low rate. Consequently great strains are given to the cells and dynamo alternately, and the engine runs far worse than it would do as a rule. The case given is supposed to be a bad one, but the difficulty occurs in many degrees. A very simple remedy is the following, when a large number of lamps are required to be used at one time:—Disconnect one of the shunt wires from the brushes, so that the cells are discharging the whole evening into the shunt circuit; such discharge rarely exceeds 3 or 4 ampères, so that a constant field is obtained by a very small loss of charge. The dynamo now gives all its current to the lamps, including the current which usually goes to its

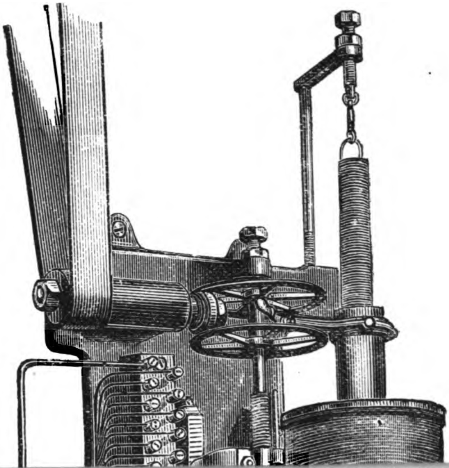


FIG. 24.—THE GOOLDEN AND TROTTER GOVERNOR.

[*To face page* 131.

shunt circuit. Thus the machine is made to give more than its nominal output without strain. The only objection is that should the engine break down, darkness results; but a simple automatic arrangement is easily made, such as a suitable combination of a small centrifugal governor with mercury cups, or by means of a properly devised electrical apparatus, so that a stoppage would restore the usual connections. The above is the very best way to work when the utmost power of an installation is needed, and the dynamo has a capacity equal to at least twice the maximum discharge rate of the accumulator. Even with smaller dynamos there are many advantages.

There is another way of working, whereby the light should be quite steady if all arrangements have been well devised—that of working at "balancing point," when the two steadying properties of the cells come into play. To work in this manner, the current flowing in the lines must remain constant, or the equilibrium is lost. An experimental run will soon decide how many lamps must be on to arrive at the required conditions.

The Goolden and Trotter governor (shown in plate 24) consists of two parts, one a solenoid, containing a core suspended by a spring. When the governor is made for constant current, the main current is passed through the coil, which has a low resistance, and the core is drawn down against the spring as the current increases, the spring raising it again for a fall in the current. When the apparatus is used for constant E.M.F., the coil has a high resistance, and is placed

between the leads, acting in the same way as when the main current was passed, since a higher E.M.F. sends more current through the coil, and *vice versâ*. The other part of the governor consists of a stepped switch connected with resistances, which are placed in the shunt circuit of the dynamo field magnets. The finger of the switch is caused to move in one direction or the other, putting resistance in or out, as the core in the solenoid is drawn down or raised in proportion to the current flowing in the coil. The actual movement of the finger is produced by the engine, and the movements of the core simply decide the direction in which the finger shall travel, and at what point this movement shall cease. The engine continuously rotates a small pulley, and the core works a lever up or down in such a way as to engage one of two bevel wheels which are fixed together, causing the shaft carrying these wheels to revolve, and by means of screw gear works the finger up or down over the contacts. There is a position of the core when engagement does not take place, then the finger remains stationary. The setting is effected by varying the strength of the spring. This governor is very sensitive, being strongly made at the same time, so it proves highly satisfactory. The diagram shows the apparatus as it appears when fixed, with its connections.

The gove .ors for counter E.M.F. were specially made for the author by Messrs. Woodhouse and Rawson, and after many improvements in the details, it has shown itself most reliable. As originally constructed, a part of the apparatus was made to oscillate continuously, by being

connected to some part of the engine, and to explain the action, we will suppose it so arranged. The oscillating portion carries two magnets, each actuating a pawl, only one acting at a time. When a pawl is drawn down by its magnet, the oscillating motion causes it to rotate a wheel fixed on the shaft which works the switch, and the arrangement is such that one pawl drawn down causes rotation one way, whilst the

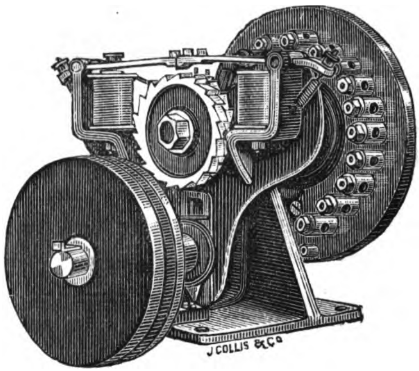


FIG. 25.—COUNTER E.M.F. GOVERNOR. GENERAL VIEW.

other one produces motion in the reverse direction, thus putting counter E.M.F. cells in or out of one of the house lines, according to which magnet on the oscillating part draws down its pawl. These two magnets receive their currents from any good form of E.M.F. regulator, such a one as described answers well, and is no more than a two-way switch, worked by E.M.F., so that the current is given to one magnet or the other, as the E.M.F. is above or below the normal,

and when the correct E.M.F. is established, the regulator finger swings between its contacts, sending no current to the governor magnets. Such an apparatus, with

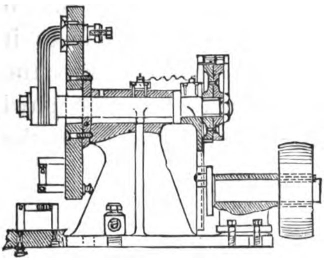


FIG. 26.—COUNTER E.M.F. GOVERNOR. SECTION.

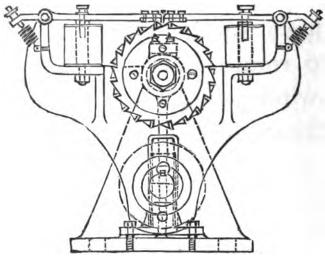


FIG. 27.—COUNTER E.M.F. GOVERNOR. BACK ELEVATION.

slight modifications, can be used in the same way as the Goolden and Trotter governor, and is then actuated by a current regulator. Figures 25, 26, 27, and 28 show the governor as arranged for counter E.M.F.

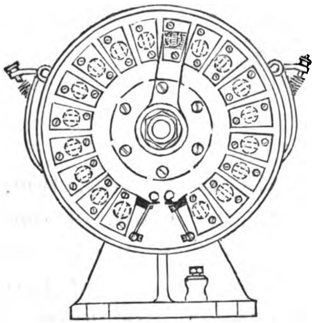


FIG. 28.—COUNTER E.M.F. GOVERNOR. FRONT ELEVATION.

To avoid running the apparatus continuously, and to admit of its acting when the engine is at rest, the following device has been added:—In the circuit of each magnet on the governor, is included a switch, worked magnetically by the current passing to these magnets. This switch starts a small motor which works the

apparatus. Thus each time a pawl is depressed the motor starts, causing it to work the switch, but when normal E.M.F. is established, and no current passes to the magnets, the magnetic switch ceases to act, and the motor stops. In practice the work done by the counter E.M.F. switch is this:—As charging proceeds, cells are put in one by one in the course of the day, and afterwards they are rapidly taken out, so the motor does not run more than one minute a day at most. With such arrangements, anxiety is removed, break-downs become practically impossible, and a steady, good light, can be obtained at all hours. Duplicates, clutches, and other complications can be completely dispensed with, excepting in those cases where the installation is very large, and more than one dynamo is required to do the work.

It is possible to construct an apparatus to put the dynamo to the cells, when the E.M.F. is just high enough to charge, by differential action, *i.e.*, difference in E.M.F. between dynamo and cells. These instruments are very sensitive, but there is not much to be gained by their use.

CHAPTER V.

ESTIMATES.

It is almost impossible to give more than a very general idea of the cost of an electric light installation, because the conditions under which they are erected differ to so great an extent. However, in order to guide those seeking such information, a careful table has been prepared, and this forms the whole of the chapter, together with the explanations necessary to understand the basis on which the results have been obtained.

Unless electrical work is thoroughly well done, and passed by competent persons other than the fire-office inspectors, who have often not sufficient practice to understand every detail thoroughly, the result is certain to be unsatisfactory. In all cases the fire-office must receive a notice of the intention of the insurer to light by electricity, and it is well to ascertain if any special requirements have to be attended to before starting the work, and thus save after-expense and trouble. If all is properly carried out there is not the remotest danger of fire, but a badly-planned installation is simply introducing a danger into the house. In the following estimates 25 to 50 per cent. margin of power has been allowed for, and this is not too much in practice, for the

machinery, etc., are not strained, and in most instances extra lamps are added at future times.

Gas is taken at 3s. 6d. per 1,000 cubic feet, coal at 20s. a ton. Each ind. h.-p. of the gas-engine is supposed to require 20 c. ft. of gas per hour, and each ind. h-.p. of a steam-engine, with fairly economical boilers, at 6 lbs. of coal per hour. The working expenses are not increased by the use of an accumulator, because, although there is a loss on one hand, there is a saving on the other, but under sinking-fund and interest an addition is made. The lamps are supposed to be the 16 c.p., requiring 60 Watts, and if 8 c.p. are used the numbers may be doubled for the lamps. In passages, etc. the smaller lamps are sufficient. The 16 c.p. lamps give nearly 20 candles. A gas burner giving the same light requires 6 c. ft. of gas per hour, and costs £2 2s. a year on the assumptions laid down in the table for 2,000 hours per year. To this must be added, damage caused by gas at 2s., per burner, interest and sinking-fund on fittings and piping, together with candles and oil, inseparable where gas is used, at 3s. per burner, making in all for single and grouped burners £2 7s. per light a year, when the gas is drawn from a public supply; but other expenses must be added for private works, such as interest and sinking-fund, the gas also will probably cost more per 1,000 c. ft.

In the consideration of an accumulator it is assumed in every case that never more than 75 lamps can be lit at once from this source alone, though the installation may be for more lamps, because it is rare that a larger

TABLE OF

No. of hours used per annum.	No. of 16 c.p. lamps in installation.	Cost of dynamo.	Fitting up dynamo, foundations, carriage, belting, switches, etc.	Nom. H.P. Otto gas engine.	I. H.P. Otto gas engine.	Cost of Otto gas engine.	Cost of carriage, erection, pipes, foundations, etc. Otto gas engine.	Cost of wiring, installation, lamps, switches, fuses, etc.	Nom. H.P. steam engine (Marshall).	Cost of Marshall engine and boiler.	Cost of steam engine, foundations, carriage, erection, etc.	Cost of simple governor.	Cost of complete governors.	Cost of automatic switches.	Cost of switch-board for accumulator and instruments.	Accumulator only.	Erection, shelves, carriage, etc.	Cost of installation, no accumulator.	Cost of installation, with accumulator.
		£	£			£	£	£		£	£	£	£	£	£	£	£	£	£
2000	25	35	15	2	4	138	32	50	...	...	...	15	70	30	40	90	10	270	415
2000	40	45	15	3½	6	174	36	80	...	...	...	15	70	30	40	162	48	350	605
2000	45	50	15	...	...	...	...	90	3	167	53	15	70	30	40	162	48	375	630
2000	50	50	15	4	8	184	36	100	...	...	...	15	70	30	40	180	50	390	665
2000	60	60	15	...	...	...	...	120	4	206	44	15	100	30	60	180	50	445	720
2000	99	90	15	7	14	225	35	180	...	...	...	15	100	30	60	243	57	545	920
2000	90	90	15	...	...	...	...	180	6	238	72	15	100	30	60	243	57	595	970
2000	120	105	20	...	...	...	...	240	8	265	85	15	100	30	60	243	57	715	1090

ESTIMATES.

Cost of auto. installation with accumulator.	Average cost per lamp, no accumulator, capital account.	Average cost per lamp, with accumulator, capital account.	Average cost per lamp, auto. installation, capital account.	Annual expense, actual outgoings, no accumulator.	Annual expense, actual outgoings, with accumulator.	Annual expense, actual outgoings, auto. installation, with accumulator.	Average annual cost per lamp, working expenses, no accumulator, no interest or sinking fund.	Average annual cost per lamp, working expenses, with accumulator, no interest or sinking fund.	Average annual cost per lamp, working expenses, auto. installation, with accumulator, no interest or sinking fund.	Annual cost, including interest and sinking fund, no accumulator.	Annual cost, including interest and sinking fund, with accumulator.	Annual cost, including interest and sinking fund, auto. installation, with accumulator.	Average cost a year per lamp, with interest and sinking fund, no accumulator.	Average cost a year per lamp, with interest and sinking fund, with accumulator.	Average cost a year per lamp, with interest and sinking fund, auto. installation, with accumulator.
£	£ s.	£	£	£	£	£	£ s.	£ s.	£ s.	£	£	£	£ s.	£ s.	£ s.
515	11 0	17	21	95	103	106	3 16	4 2	4 4	105	136	146	4 4	5 10	6 0
705	9 0	14	18	124	137	142	3 6	3 9	3 10	150	184	194	3 15	4 10	5 0
730	8 0	13	16	137	150	155	3 1	3 6	3 9	164	200	210	3 15	4 9	4 10
765	8 0	13	15	148	161	166	3 7	3 12	3 18	178	214	224	3 12	4 4	4 10
850	7 5	12	14	167	180	185	2 15	3 0	3 2	200	239	252	3 7	4 0	4 3
1050	6 0	10	12	230	250	256	2 9	2 15	2 15	270	322	335	3 0	3 10	3 14
1100	6 5	11	12	232	252	258	2 9	2 15	2 15	277	329	342	3 0	3 12	3 15
1220	6 0	9	10	292	312	318	2 8	2 11	2 13	345	401	414	2 16	3 7	3 9

call is necessary, and the weight and expense rise considerably when heavier discharges are required. Any number of lamps may be installed, but no more may be in use at any one time than the maximum for which the installation was intended. The steam-engines are all given of higher power than necessary, which permits a large margin for variations in boiler pressure, so as never to be short of steam; also the power delivered at maximum varies with steam pressure, and this gives a reserve. Under the ordinary conditions here assumed, £2 per lamp has been allowed for wiring, switch, lamp, holder, and fuse, also simple fittings. Elaborate fittings are not required, so that the cost of these must be added as the taste of the owner may dictate. Since the prices for dynamos, engines, wire, and all electrical requisites are much the same at all the chief manufacturers, there is no reason for choosing one maker more than another, provided the most suitable and best articles are always obtained, remembering that some manufacturers make a speciality of certain classes of goods, and in order to secure the most modern and durable articles throughout several firms should be employed.

Some object to so many automatic appliances, but the objection is unreasonable, because failure scarcely ever occurs; and should this happen, we are no worse off than if they had not been there; a cut-out going indicates the event, and no harm is done. Mankind fails a hundred times to one, at least, compared with a mechanical contrivance.

CHAPTER VI.

A BRIEF ACCOUNT OF THE BROOMHILL INSTALLATION.

November, 1887.

ELECTRIC lighting was commenced in an elementary manner in 1874, with primary batteries, to obtain a better light in the workshop at night. About a year later a Gramme dynamo was used. From that time till 1881 continued advance was made in electrical science and apparatus connected with it; it was therefore deemed advisable to make no changes till electric lighting appeared to be in a more settled condition, and in that year it seemed to be the case.

In 1881 the Broomhill installation underwent a change, a 16-candle Jablochkoff dynamo with self-contained exciter was erected.

The following year (1882), much attention was given to accumulators for a public supply; and one of the earliest ones made was sent to Broomhill for lighting purposes, by the Electrical Power Storage Company. In fact, till 1883 there was no really good cell made—and the present ones are much the same; but they now last well, compared with the earlier ones, which is almost

entirely due to a better knowledge of management—and this is the secret.

Broomhill saw three distinct installations between September, 1882, and September 1883. The Jablochkoff dynamo disappeared, a Siemens 60—20 c.p. 50-volt machine was erected, and lamps placed in the private sitting-rooms of the house. In February, 1883, this was changed for a 100-volt dynamo, and great advantages accrued in consequence. A better light was obtained, and the number of lamps could be increased slightly. Four gas engines were put up during this period. In March, 1883, another installation was erected with a 6 h.-p. steam engine and two 50-light Siemens machines coupled. This installation ran admirably till November, 1883. Breakdowns occurred at first, for want of water to feed the boiler; this was eventually remedied, and all went smoothly.

The first accumulator was put up in the Autumn of 1883, and a great blessing it proved.

This battery consisted of what was then termed 1 e.h.p. cells, fifty-five in number. Endless devices were made in the workshop to render everything automatic, and at last this was accomplished.

After the knowledge gained, it was decided to put up a model installation; this was done, and no hitch of any kind has ever occurred since its start in the summer of 1884.

It may be remembered that some time about September, 1883, the Electrical Power Storage Company declined to supply any more cells for a time, because

some improvements had been found possible, which in the end turned out to be "castles in the air." Broomhill, however, profited by this circumstance, for the Company undertook to supply a new battery free of expense if the first one failed, and eventually it broke down. In August, 1884, the new accumulator came—cells of the same size as before, but with thick plates, such as are now termed "Regulator type."

This accumulator again proved unsatisfactory, and arrangements were made to exchange for a new set of cells of the hanging type, with plates of the size termed "L." A new accumulator room was built to receive them, and everything in it modified to suit the purpose.

In August, 1885, this set of cells was erected.

The engines, etc., are all in duplicate, and large enough to meet the heaviest load likely to be put on; there are five dynamos, three of which can do all the work required singly, and two for arc lighting; there are also about twenty motors.

In order to put up a larger accumulator, consisting of 108 cells, a new place was built in 1886, containing many improvements; and, as far as can be seen, no drawback of any kind exists.

The convenient plan of placing resistances in the dynamo shunt circuit, to vary the E.M.F., was probably for the first time used at Broomhill, as well as the counter E.M.F. regulating methods.

There are about 500 lamps, *i.e.*, equal to 500 16 c.p. lamps, for many are 100, 50, 32, and 10 c.p.; the E.M.F. employed is 100 volts. The greatest

number of lamps used at any one time has rarely exceeded 200, and, together with these, the arc lamp taking forty to fifty ampères, and one or two motors. Stables, cellars, etc., are all lit electrically, so that no gas is used except for heating, cooking, and laboratory work. The switches in every case are placed upon the door-posts. Every possible kind of work in metal or wood, from watchwork to large constructions, can be done in the workshop by means of machinery worked by motors. Photography is also practised by electric light. Numberless devices are in use about the house and elsewhere, taking advantage of the benefits of the current for every conceivable purpose. All the electrical arrangements in and out of the engine-house are automatic; and the whole of the buildings, electrical and engineering work, were carried out by the owner without assistance, and by men trained on the spot.

The installation is fitted up throughout in a most perfect manner, and the buildings are very substantial and well fitted. The maximum power is 1,000—16 c.p. lamps when both engines are running, and now there are 108 cells at work. The cost of the buildings and installation has been about £6,000, or much the same as a gasworks; to do the same work, perhaps the latter would have been more costly. The sinking fund in either case would be much the same. But the working expenses of the electric light has proved more favourable than of gas. This statement is made authoritatively, for there was a private gasworks at Broomhill, before the electric light was instituted. It

was at one time a question between building larger gas-works or adopting the new light, and calculations decided in favour of the latter, and practice has proved it since. There is a book kept of every penny spent on the light, as well as the number of ampère hours used. This cost-book has been accurately kept for the past three years, and runs thus:—For 1884 the total outgoings amounted to £165, being at the rate of 2d. an hour for every 16 c.p. lamp; in 1885 the expenses were £181, or 1½d. per hour per 16 c.p. lamp; the total expenses in 1886 were £210, being at the rate of ⅓d. per 16 c.p. lamp. The expenses include wages, coal, oil, waste, washers, repairs, lamp renewals, etc. A six cubic feet gas burner costs ½d. an hour when gas is sold at 3/6 per 1,000 cubic feet, so that in 1886 the electric light proved far cheaper than its rival, had a private gasworks been used. The reason why the expenses went up in each year, and at the same time the economy increased, is due to two causes:—firstly, as confidence in the electric light increased, it was used more and more, and finally, without stint, so that the installation was gradually worked nearer the point of greatest economy; and secondly, numbers of improvements were introduced, in the way of management as well as apparatus, which led to the beneficial results.

Probably over £2,000 has been expended in experiments, before arriving at the present satisfactory position.

The expense of this installation may be divided into. five parts. Each complete working half cost £1,500; the cells, £500, including all their fittings; extra dynamos,

machinery, etc. etc., £1,000; the engine-house buildings, which are extensive, £1,000; and for testing apparatus, lamps, wires, motors, etc., £500; making a total of £6,000 or thereabouts. For this year, 1887, to the end of October, the expense has been at the rate of $\frac{5}{8}$d. per 16 c.p. lamp per hour, and considering that for at least five months the family was away, and no current used, this result is very good, for during the slack time expenses went on just the same, the only saving being in coal. This cost is far below what it has ever been before for the first ten months of the year. During the last two months a great deal of current is used at an extra expense of about twenty shillings a week for coal and oil, so the cost per lamp is brought down to the annual low average in this way; what the figures will work out at by January 1st, 1888, time alone can prove. The probable question of cost has been fully discussed in a separate chapter, so there is no need to speculate here, and so we must abide a few months to be told a truthful tale.

INDEX.

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